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FISH/FORESTRY INTERACTION PROGRAM

This study was undertaken as part of the Fish/Forestry Interaction Program, a multidisciplinary research study initiated in 1981. The program was started following a series of major winter storms in 1978 that triggered landslides over much of the Queen Charlotte Island forest land base. Originating on steep slopes, many slides deposited tonnes of debris in streams and on valley flats. The events raised private and public concerns over logging practices on the islands and prompted the establishment of the 5 year program. Overall objectives of FFIP were:

- to study the extent and severity of mass wasting and to assess its impacts on fish habitat and forest sites.
- to investigate the feasibility of rehabilitating stream and forest sites damaged by landslides.
- to assess alternative silvicultural treatments for maintaining and improving slope stability.
- to investigate the feasibility and success of using alternative logging methods, including skylines, helicopters, and by logging planning, to reduce logging-related failures.

The program is jointly funded by direct appropriations from the Canada Department of Fisheries and Oceans, the B.C. Ministry of Forests (Research Branch), and the B.C. Ministry of Environment (Fisheries Branch). Participating agencies include the Canadian Forestry Service (Pacific Forestry Centre) and the Forest Engineering Research Institute of Canada (FERIC), Vancouver, B.C.

Program results are published through the B.C. Ministry of Forests, Land Management Report Series as well as papers presented at symposiums, conferences and through technical journals.

For information about the program contact Ministry of Forests, Research Branch, 1450 Government Street, Victoria, B.C. V8W 3E7.

Soils, Vegetation, and Forest Growth on Landslides and Surrounding Logged and Old-growth Areas on the Queen Charlotte Islands

by

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ABSTRACT

A synoptic survey of 49 landslides ranging in age from 1 to 155 years was conducted to compare revegetation patterns and forest productivity with surrounding logged and old-growth stands. The landslides left a chaotic mixture of logs, rocks, and soils of varied proportions, further complicated by additional materials eroded from the slide edges following initial failure. The upper portion of slides was partially scoured to bedrock or more rarely to a compact glacial till, whereas the lower portion mainly consisted of slide material deposited on or mixed with original soil. Effective soil depth on the upper two-thirds of the slides was significantly less than in the lower third or in the adjacent, non-slide surround. Bedrock exposure on slides amounted to 8, 10, and 2% for upper, middle, and lower slope positions, respectively, as compared with 1, 1, and 0% for non-slide terrain. For all slides and slope positions combined, exposed mineral soil and bare bedrock averaged 88% at 4 years after failure and 14% at 90 years. The reduction in bare bedrock and mineral soil exposure occurred more rapidly on lower than middle or upper slopes.

Soils on non-slide areas were chiefly Orthic or Gleyed Ferro-Humic Podzols. Soils on slides were severely perturbated but, in addition to the Orthic Regosols, many were recognized as Dystric Brunisols and Gleyed and Orthic Ferro-Humic Podzols. Organic carbon contents in mid-slide soils were high (avg. = 4 to 8%). Vegetation development on these soils should be considered as secondary rather than primary in nature.

Two major trends in vegetative development on slide surfaces were observed, one dominated by red alder (Alnus rubra)and one dominated by conifers. The former was most common on the lower portion of slides, particularly those occurring in low elevations on material derived from fine-textured bedrock or those with a relatively high calcium content. Conifers tended to dominate on the middle and upper portions of slides, especially in high elevations on relatively coarse and acid soil material. Initial revegetation was dependent upon the availability of stable mineral soil microsites and islands of debris and other remnant organic material.

Vegetation on slides was classified into eight groups and on logged areas into three groups based on dominant plants. The groups particularly reflected stages of development, degree of red alder invasion, and type and stability of substrate.

Revegetation in logged areas differed from the adjacent slides largely as a result of a higher component of western hemlock (Tsuga heterophylla), lower stocking of red alder, and a greater proportion of stable microsites. Logged areas produced about 3 times the volume of wood than slides in the same (30- to 59-year) age class. A lack of older logged stands in the study precluded direct comparisons at later stages. However, based on appropriate yield tables it was estimated that the oldest group of slides, averaging 85 years of age, had produced about one-half the wood volume (conifer and red alder) of normal second-growth stands of the same age.

ACKNOWLEDGEMENTS

Personnel of several forest companies arranged camp accommodation, gave advice on landslide locations and expedited the study in various ways. These included Gary Marshall (CIPA), Ron Bronstein (Western Forest Products), Steve Chatwin, Jerry Johnson, Paul Chapman, and Jim Sears (MacMillan and Bloedel) and Ron Frank and Gilbert Brennenstuhl (Crown Forest Industries). Jim Schwab, Dr. Howard Stauffer, and Dave Wilford (B.C. Ministry of Forests) and Keith Moore (B.C. Ministry of Environment) provided especially useful technical advice. Bruce Thomson and Frances Noone (B.C. Ministry of Environment) helped identify rock samples. Dr. W. Schofield (UBC) identified our difficult bryophytes and Drs. R. Ogilvie and A. Ceska (Provincial Museum) provided advice on other plant species. Dr. Jim van Barneveld and Lori Bishop (B.C. Ministry of Environment) and Dr. Clarence Simmons (Canadian Forestry Service) assisted in analyzing our vegetation data. Their patience and goodwill are much appreciated.

Assistance in the field in 1981 was ably led by Trudy Carson, aided by Mary Morris and Steve McNaughton. Ed Wass (Canadian Forestry Service) greatly assisted us on analyses of data, soils, and wood samples.

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TABLE OF CONTENTS

ABSTRACT..... iii

ACKNOWLEDGEMENTS..... v

1 INTRODUCTION..... 1

2 STUDY DESIGN AND METHODOLOGY..... 3

2.1 Description of Variables 3

2.2 Field Techniques..... 7

2.2.1 Transects..... 7

2.2.2 Vegetation sampling..... 9

2.2.3 Soil description..... 10

2.3 Soil Analyses..... 11

2.4 Statistical Procedures 11

3 RESULTS..... 12

3.1 Surface Conditions of Slides and Adjacent Non-Slide Surrounds..... 12

3.2 Soil Features..... 20

3.2.1 Surface organic layer..... 20

3.2.2 Mineral soil..... 20

3.2.3 Soil classification..... 29

3.3 Vegetation Development..... 30

3.3.1 General vegetative cover..... 30

3.3.2 Deer browsing..... 42

3.3.3 Tree stocking and composition by number of stems..... 45

3.3.4 Tree composition by basal area..... 48

3.3.5 Vegetation groups..... 49

3.4 Forest Growth and Site Productivity..... 64

3.4.1 Early height growth rates of trees..... 64

3.4.2 Basal area production..... 65

3.4.3 Wood volume production..... 68

4 DISCUSSION..... 73

5 SUMMARY..... 81

6 LITERATURE CITED..... 83

APPENDICES

1 Characteristics of failures and their surrounds..... 88

2 List of plant species recorded..... 91

TABLES

1 Slope, soil depth, and bedrock exposure by slope position for slides and adjacent surround..... 15

2 Cover of natural (rotting) logs and recent slash on slide and surround surfaces..... 15

3 Types of organic surface horizons by age class of logged areas and for old-growth stands..... 18

4 Types of organic surface horizons by age class of slides..... 19

5 Comparisons of several characteristics of surface organic horizons on slides (Sli.) with those on adjacent surrounds (Sur.)..... 22

6 Mean particle size distribution of the fraction less than 2 mm on the basis of rock type for mid-slide and undisturbed surround combined..... 25

7 Mean pH for mid-slide and undisturbed mineral soil on the basis of rock type..... 26

8 Mean percentages of organic carbon and total nitrogen and C:N ratios for mid-slide, logged and old-growth mineral soil as subdivided by rock type..... 28

9 Total vegetative cover for upper, middle, and lower slope positions for slide, logged, and old-growth plots..... 33

10 Total cover of vegetation, red alder, western hemlock, Sitka spruce, western redcedar, and all conifers on slides for each associated rock type..... 35

11 Total cover of vegetation, red alder, western hemlock, Sitka spruce, western redcedar, and all conifers on logged areas for each associated rock type..... 37

12 Total cover of vegetation, red alder, western hemlock, Sitka spruce, western redcedar, and all conifers in old-growth stands for each associated rock type..... 38

13 A comparison of mean browse ratings for major trees, shrubs, and herbs for slide, logged, and old-growth stands..... 43

14 A comparison of mean browse ratings among species on slide, logged, and old-growth areas..... 44

15 Stocking of major tree species for slide, logged, and old-growth stands..... 46

16 Percentage composition of major tree species for slide, logged, and old-growth stands based on number of stems of all sizes..... 46

17 Percentage composition by basal area for major tree species for slide, logged, and old-growth stands..... 49

18 Number of plots, average age, average total vegetative cover, and common plant species for vegetation groups, older logged plots, and old-growth..... 51

19 Mean basal area for major tree species for slide and logged stands up to 55 years of age..... 66

20 Basal area of live trees for slide, logged, and old-growth stands by age class..... 67

21 Mean basal area of dead, standing trees for all slide, logged, and old-growth plots..... 69

22 Volumes of live trees for slide, logged, and old-growth stands by age class..... 70

23 Comparison of volumes of trees in old slides (>60 yr) with those in old-growth stands (>150 yr)..... 71

Soils, Vegetation, and Forest Growth on Landslides and Surrounding Logged and Old-growth Areas on the Queen Charlotte Islands

Land Management Report NUMBER 41

ISSN 0702 9861

July 1986

BC

FIGURES

1 Location of Queen Charlotte Islands off the coast of British Columbia..... 2

2 A recent, open-slope, debris avalanche..... 4

3 Use of border-tree increment cores as an aid in dating landslides. A. Estimated year of slide (1958) followed by period of slow radial growth. B. Estimated year of slide (1963) followed by period of rapid radial growth 6

4 Transect and vegetation plot sampling scheme on a debris avalanche..... 8

5 Locations of landslide study areas on the Queen Charlotte Islands..... 14

6 Percentage cover of exposed soil and bedrock as a function of slide age and slope position (U =Upper; M =Middle; L =Lower). R^2: U =0.53; M =0.47; L =0.86..... 17

7 Acidity of surface organic layers as a function of slide age (pH measured in H_2O and 0.01 M $CaCl_2$). R^2: H_2O=0.27; $CaCl_2$ = 0.34 21

8 Organic carbon and total nitrogen concentrations of surface organic layers as a function of slide age. R^2: Carbon=0.65; Nitrogen=0.58..... 21

9 Percentage coarse fragments (>2 mm) by visual, volume estimate for mid-slide and undisturbed soils as a function of soil depth..... 23

10 Percentage coarse fragments (2 mm to ca. 20 mm) by weight of collected samples for mid-slide and undisturbed soils as a function of soil depth..... 23

11 Percentage sand, silt, and clay in the mineral soil fraction (<2 mm) of collected samples for mid-slide and undisturbed soils as a function of soil depth..... 24

12 Average pH (H_2O) for mid-slide and undisturbed mineral soils as a function of soil depth..... 27

13 Proportions of podzols versus regosols with increasing time since landslide and a comparison with logged and old-growth surrounds..... 30

14 Total vegetative cover on slides as a function of age and slope position (U =Upper; M =Middle; L =Lower). Plotted points are averages of stands within each age class..... 31

15 Total vegetative cover as a function of age for slides and logged areas. Plotted points are averages of stands within each age class..... 32

16 Average composition and structure of stands on slides 30-79 years of age: A. Upper slope, granitic, coarse conglomerate, and hard volcanic bedrock; B. Upper slope, fine sedimentary, calcareous, and soft volcanic bedrock; C. Lower slope, granitic, coarse conglomerate, and hard volcanic bedrock; D. Lower slope, fine sedimentary, calcareous, and soft volcanic bedrock..... 36

17 Cover of red alder on slides as a function of slide age and slope position. Plotted points are averages of stands within each age class. 39

18 Total cover of conifers on slides as a function of slide age and slope position. Plotted points are averages of stands within each age class..... 39

19 Average composition and structure of stands 30-59 years of age: A. Upper slope, slide; B. Upper slope, logged; C. Lower slope, slide; D. Lower slope, logged..... 40

20 Bryophyte cover on slides (S), logged areas (L) and in old-growth stands (OG) as a function of age..... 41

21 A 45-year-old slide with a sparse stocking of conifers in the upper portion (foreground) and a dense cover of red alder in the lower portion..... 47

22 Relationships among the eight slide vegetation groups and old growth. G = Group 54

23 Early height growth of red alder, western hemlock, and Sitka spruce in slide (S) and logged (L) areas. R^2 for all regressions >0.99..... 65

24 Average composition and structure of stands: A. Upper slope, slides >80 years of age; B. Upper slope, old-growth; C. Lower slope, slides >80 years of age; D. Lower slope, old-growth..... 72

1 INTRODUCTION

Landslides are a natural and common feature throughout much of the northwest coast of North America (Swanston and Swanson 1976). However, logging operations are known to increase the frequency of landslides (Bourgeois 1978; Sidle et al. 1985) and concern about the impact of this acceleration on water and fish led to the institution of the Fish Forestry Interaction Program (Poulin 1985). This program concerns impacts of landslides on fish habitats and forest sites in the Queen Charlotte Islands (Fig. 1). This report addresses the impact of landslides on forest sites.

In addition to their potential adverse effects on fish habitat, landslides may affect forest productivity through destruction of established forest stands, delays in restocking, and decreased growth rates after stand establishment. Improved knowledge of productivity effects will aid in predicting realistic wood yields and calculation of future annual allowable cut rates in areas susceptible to mass wasting. Additionally, knowledge of natural vegetative succession on mass-wasted areas is basic to the planning and implementation of rehabilitation efforts, both on slides and in streams.

The specific objectives of the study were:

1. To study soils, vegetation, and forest growth on landslides of varying age and site features and in adjacent logged areas and old-growth stands.
2. To elucidate soil and vegetation development on landslides and logged areas.
3. To determine the productivity of landslides for tree growth in comparison with logged areas.

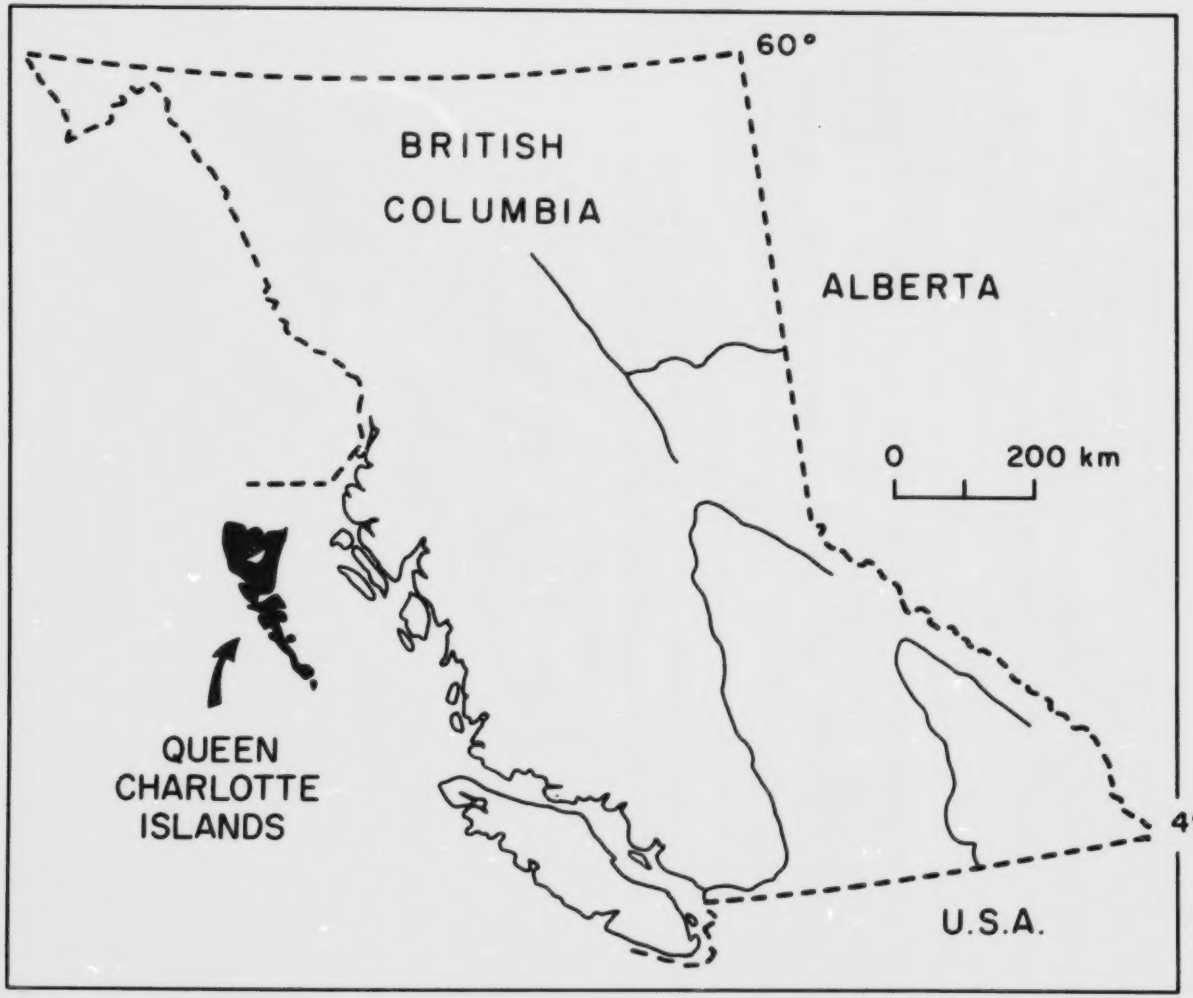

FIGURE 1. Location of Queen Charlotte Islands off the coast of British Columbia.

2 STUDY DESIGN AND METHODOLOGY

2.1 Description of Variables

Forty-nine landslides, mainly open-slope debris avalanches (Swanston 1974), were selected for study (Fig. 2, Appendix 1).[1] Slides selected for study were mainly of the open-slope variety, although three V-notch, debris torrents were also included (Appendix 1). Selection of sites took into account the following variables:

1. Bedrock Type. Eight bedrock formations described by Sutherland Brown (1968) were encountered in or adjacent to the sample landslides. Because most of these have a diverse lithology, classification by bedrock type was based on collected bedrock and surficial rock samples in addition to the mapped information. The rock types were consolidated into seven categories:
   a. Granitic (mainly Post-tectonic Plutons)
   b. Conglomerate and Coarse Sandstone (mainly Honna formation)
   c. Soft Volcanics (mainly rhyolites and andesites of the Masset and Yakoun formations)
   d. Hard Volcanics (mainly basalts of the Karmutsen formation)
   e. Calcareous (any type with minerals reacting positively to dilute HCl)
   f. Fine Sedimentary (mainly Kunga and Haida formations)
   g. Mixtures (more than one rock category but always including a Fine Sedimentary component).

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[1] Locations of all slides are plotted on topographic maps and aerial photographs in the following unpublished report on file at the Pacific Forestry Centre, Victoria, B.,C.: Smith, R.B., P.R. Commandeur, and M.W. Ryan. 1983 (Revised). Locations of and basic data for landslides studied during forest growth investigations (EP 862-2-7).

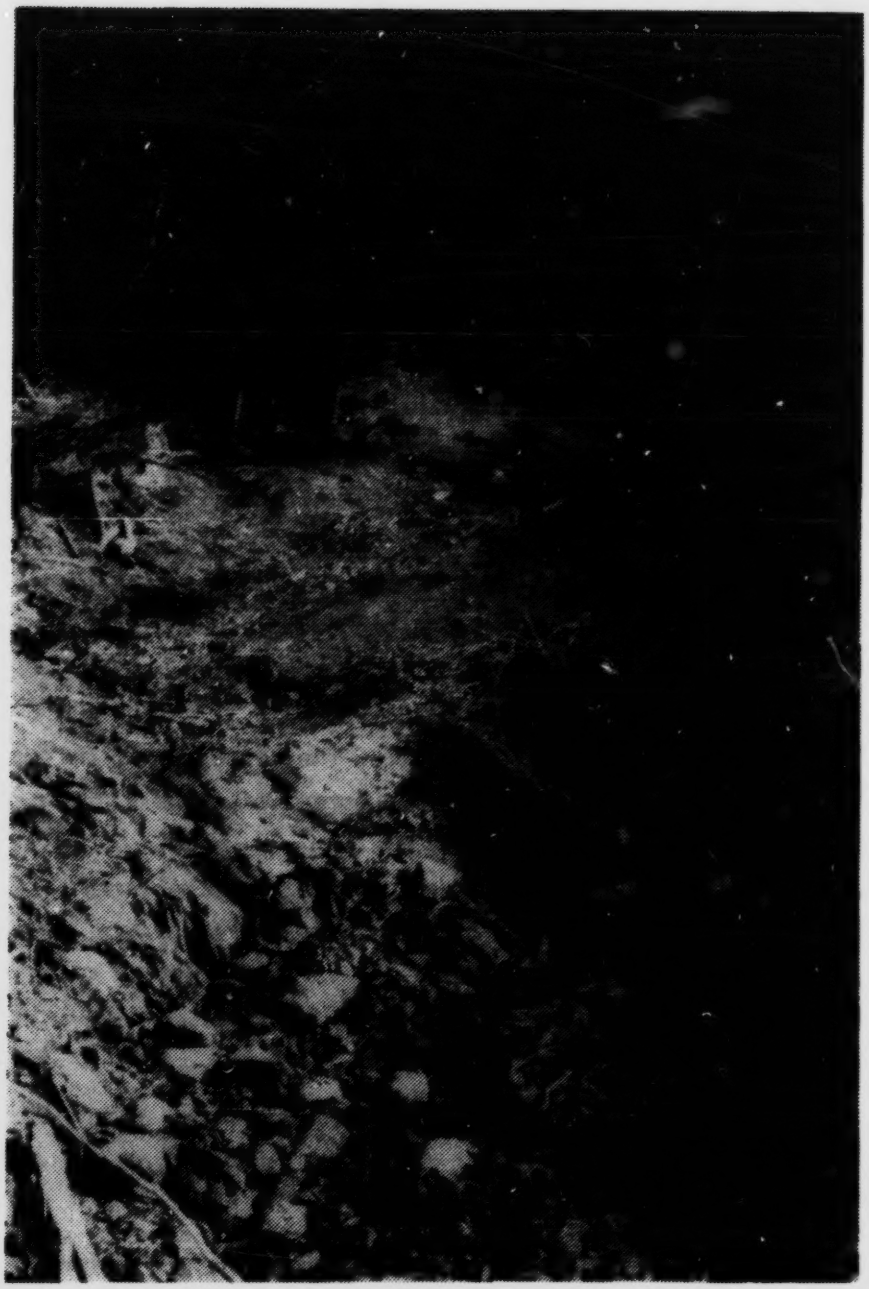

FIGURE 2. A recent, open-slope, debris avalanche.

2. Biogeoclimatic Zone. Within the Queen Charlotte Islands Hemlock-Cedar-Spruce Subzone of the Coastal Western Hemlock Zone (CWHg), slides were sampled in the submontane variant (CWHg1) with elevations to about 350 m and the montane variant (CWHg2) ranging in elevation from about 350 to 600 m (Banner et al. 1986). Slides were also studied in the Coastal Cedars-Pine-Hemlock Zone (CCPH) (Pojar 1983).[2] One slide occurred in a location transitional to the Mountain Hemlock (MH) Zone (Pojar 1983).
3. Slide Age. Ages were taken from historical records or were estimated by utilizing a combination of the age of the oldest post-slide tree sampled and the growth-ring pattern of adjacent trees affected but not killed by the slide (Terasmae 1975). Border-tree, increment cores were studied with emphasis on growth rings laid down around the time of establishment of the oldest slide trees. The point of any abrupt change in ring pattern occurring at or before the date of establishment of the oldest slide tree was deemed to represent the year of the slide (Fig. 3). A sudden decrease in ring widths (Fig. 3A) might result from a loss of a portion of the tree's root system or an increase (Fig. 3B) from a release from suppression.
4. Type of Surrounding Vegetation. Two general types were recognized:
   a. Old growth - from 150 to ca. 1000 years of age
   b. Logged - from 1 to 55 years since logging.
5. Surficial Material. Major materials were colluvial, morainal, organic, or some combination of these.
6. Type of Landslide. Landslides were initially categorized (Appendix 1) as in Swanston (1974) as follows:
   a. Debris slide. Rapid, downward movement of unsaturated, relatively unconsolidated soil and forest debris.
   b. Debris avalanche. Similar to debris slide but with a higher soil water content and usually with a greater runout zone.

---

[2] The CCPH Zone has recently been assigned to the CWH Zone as a subzone (pers. comm. from D. Meidinger, B.C. Ministry of Forests).

c. Debris flow. Rapid, downslope movement of water-saturated soil and debris by true flow processes. Often associated with debris avalanches and thus categorized with them.

d. Rotational slump. Downward and backward rotation of a soil block with a minimum of lateral movement.

e. Debris torrent. Debris flows occurring in well-defined drainage channels, e.g., the bedrock-controlled, V-notch gullies of Schwab (1983).

In subsequent data summaries the first four categories were combined and only the debris torrents treated separately. Other than the rarely encountered rotational slump, all these types of mass wasting result in destruction of nearly all of the original vegetation (Fig. 2).

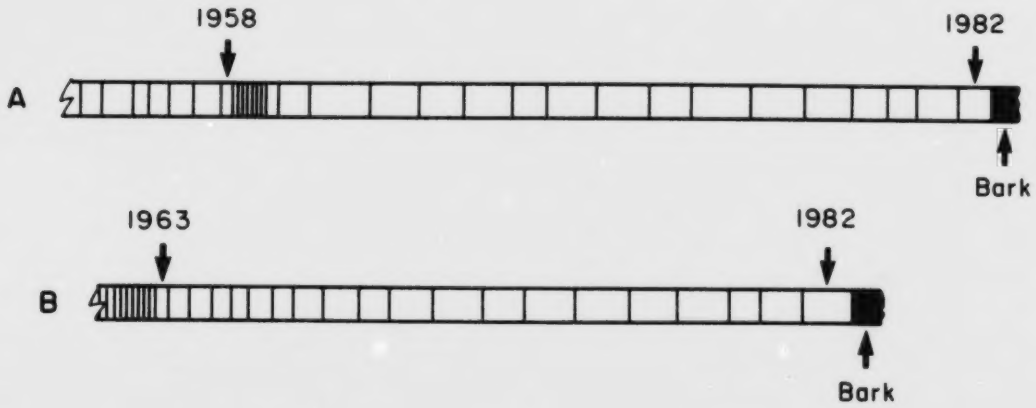

FIGURE 3. Use of border-tree increment cores as an aid in dating landslides. A. Estimated year of slide (1958) followed by period of slow radial growth. B. Estimated year of slide (1963) followed by period of rapid radial growth.

2.2 Field Techniques

2.2.1 Transects

To aid in quantitative analysis of site factors associated with slides and non-slide terrain, one or two transects were run across the slide in each of the upper, middle, and lower thirds at a right angle to the direction of the slide and 20 m into the unaffected forest (referred to hereafter as the "surround") on each side of the slide (Fig. 4). A total of 131 transects were surveyed, none on the three Kaisun slides (Appendix 1). At intervals of 3 to 10 m along each transect on the slide and at 3-m intervals in the surround, points were described as follows:

1. Soil depth (including humus) to bedrock or an otherwise impenetrable layer, measured by hammering a pointed steel probe into the ground with a sledge hammer and recorded as over 1 m or, if less than 1 m, as actual depth.
2. Surface organic layer depth including mixtures of mineral and organic particles (Ah layer), if present, as over 10 cm or under 10 cm.
3. Surface organic layer type as mainly rotten wood, mainly humified material (FH), a mixture or layered combination of the two, mineral soil plus pedologically incorporated organic matter (Ah), or litter only.
4. Mineral soil exposure type as undisturbed, gouge, or deposit.
5. Mineral soil exposure depth as shallow (<5 cm), deep (5-25 cm), or very deep (>25 cm).
6. Mineral soil exposure cause, e.g., yarding, mass wasting, surface erosion, and windthrow.
7. Slash as fine (<5 cm diameter) or coarse (>5 cm diameter).
8. Slope in percent.
9. Aspect in azimuth degrees.
10. Moisture regime as a qualitative assessment based mainly on soil depth and texture, surface form, vegetation, and presence of saturated soil and classified from dry to wet as xeric (1), submesic (2), mesic (3), subhygric (4), or hygric (5) (Pojar 1983).

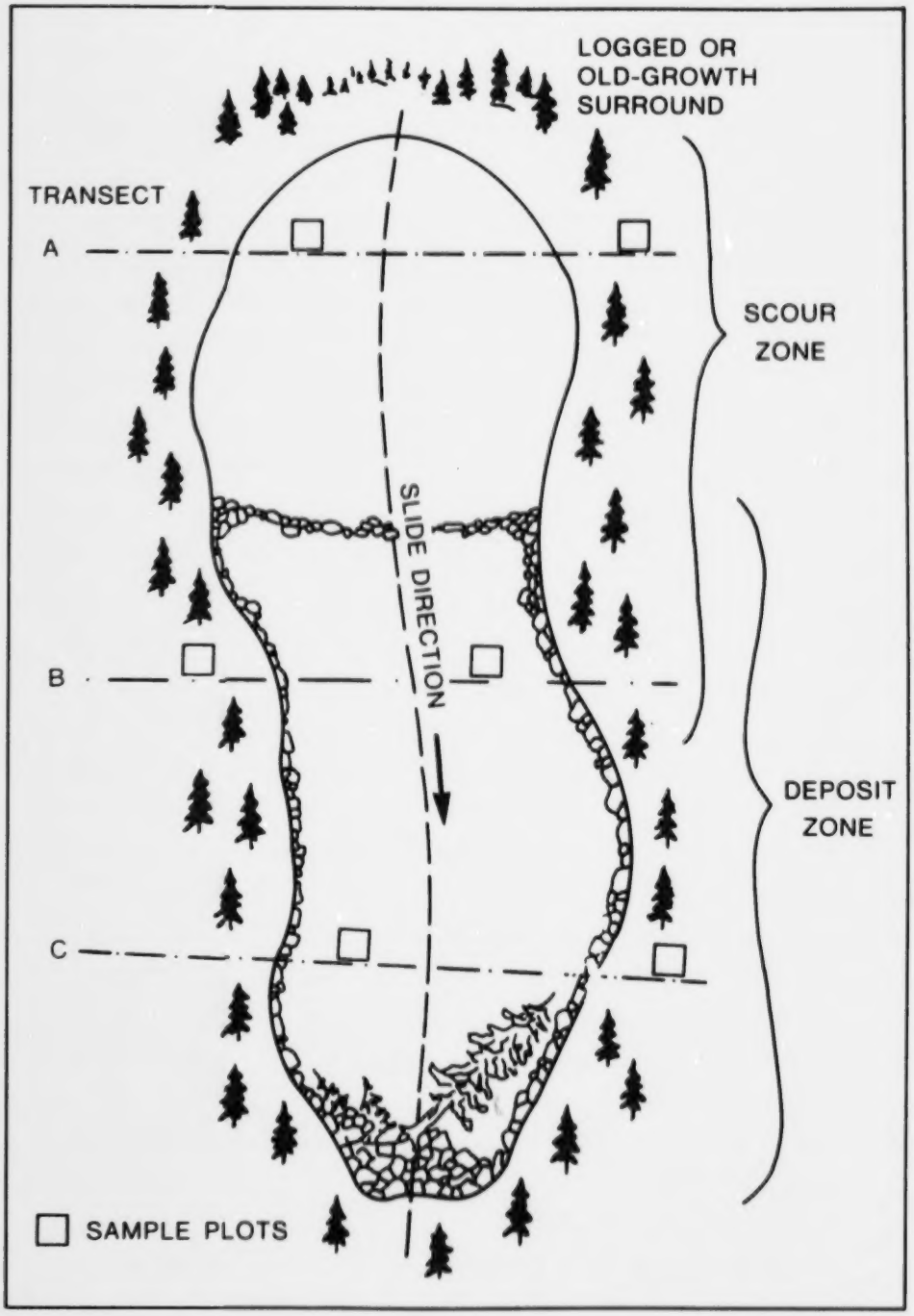

FIGURE 4. Transect and vegetation plot sampling scheme on a debris avalanche.

11. Micro-relief (surface shape) as strongly concave (0), concave (1), slightly concave (2), neutral (3), slightly convex (4), convex (5), or strongly convex (6).
12. Other substrates, e.g., stump, root, bedrock, boulder (>25 cm diameter), and stone (10-25 cm diameter).

Observations were recorded at 1874 points on slide surfaces and at 1773 points on non-slide surfaces.

2.2.2 Vegetation sampling

On each transect, at least one 4 x 4-m vegetation plot was established in the slide (156 in all) and one in the non-slide area (122 in all) (Fig. 4).

Vegetation description followed Walmsley et al. (1980). Vegetation was assessed on the whole plot as follows:

1. Percentage cover for each vegetation layer and total cover of vegetation, bare mineral soil, slash, and rotting debris.
2. Cover class in percent and spatial distribution, for all species; and height class for trees, shrubs, and herbs (Walmsley et al. 1980).
3. Browse utilization for herbs and shrubs as 0 (no utilization), 1 (1-5% of plant browsed), 2 (6-25%), 3(26-50%), and 4 (>50%) (Walmsley et al. 1980).

Within all plots data on tree growth were collected as follows:

1. For stands with trees under 1.3 m height only, trees were counted by species and a range of tree heights given. For each species, two healthy, dominant or codominant sample trees were cut and measured for total height, annual height-growth increments, and age. Basal discs were collected from the cut trees for accurate age determination. In logged stands, advance and post-logging regeneration were separately noted when this was possible.

2. For stands with trees greater than 1.3 m height but less than 7.5 cm dbh (diameter at 1.3 m height), data were collected as for (1) above except that for all trees greater than 1.3 m, individual diameters and heights were measured or estimated. For each species, two healthy, dominant or codominant sample trees were cut and total height and up to 10 recent height-growth increments measured. Including trees less than 1.3 m height, over 400 trees were cut down and sampled in this manner.
3. For stands with trees greater than 7.5 cm dbh, variable (wedge prism) plots (111 in all) centered on the vegetation plots were established to collect mensuration data additional to those described in (1) and (2). Increment borings and height measurements were taken for two dominant or codominant trees of each species. For trees within the prism plots not specifically measured, heights were estimated in the field using the measured trees as guides. Tree volumes were computed using B.C. Ministry of Forests volume equations (Watts 1983).

2.2.3 Soil description

At least one soil pit was dug, described, and sampled in the undisturbed area adjacent to the slide and one in the slide, both about midway between the bottom and top of the failure. Description and sampling followed standard methods (Canada Soil Survey Committee 1978; Walmsley et al. 1980). Soil temperatures were taken in freshly exposed soil pit walls at depths of 10 and 50 cm with a dial-head, soil-probe thermometer. Rock samples were collected from bedrock and as loose rock from soil pits.

2.3 Soil Analyses

Soil samples (366 in all) collected from pits were subjected to analyses as follows:

1. Particle size. Samples were dried, sieved, and the fraction over 2 mm weighed and expressed as a percentage of the total sample weight. Texture of the fine fraction (<2 mm) of selected samples was determined by the Bouyoucos hydrometer method (McKeague 1978).
2. Acidity. The pH of the fine soil fraction was determined potentiometrically in a 0.01 M $CaCl_2$ solution and in H_2O (McMullan 1971).
3. Color. Color of the fine fraction was determined in both the moist and dry states using Munsell Color Charts.
4. Organic carbon. Organic carbon content was determined for the oven-dry, fine fraction by the LECO Induction Furnace Method (McKeague 1978).
5. Total nitrogen. Total nitrogen content was determined for the oven-dry, fine fraction by an automated, semi-micro Kjeldahl method (McKeague 1978).
6. Extractable iron and aluminum. A procedure using sodium pyrophosphate was used to determine percent extractable iron and aluminum on 84 samples (McKeague 1978).
7. Podzol test. A rapid test using sodium fluoride was conducted on 70 samples to differentiate podzolic from other soil horizons (Brydon and Day 1970).

2.4 Statistical Procedures

Comparison of slide and surround surface soil characteristics and features of vegetation within the various categories of rock type, zone, and age class were made using a variety of statistical procedures including multiple range tests and covariance analyses. To adjust for unequally replicated means in Student-Neuman-Keuls' and Duncan's multiple range tests, critical values were multiplied by a value that accounts for

the different number of observations per treatment (Steel and Torrie 1980). Linear regression analyses were performed to determine trends with time for slide and for surround parameters. For each group regression, an F statistic and corresponding probability, the regression coefficients and t statistics, and probabilities and a coefficient of determination (R^2) were produced. An analysis of variance was performed to test for homogeneity of regression coefficients across groups. A significant F ratio indicated that the slopes or intercepts of the group regression lines differed beyond chance. Soil temperature differences between slide and surround were tested using a paired-difference test (Mendenhall 1975). Differences were considered significant at the 0.05 level in all analyses.

The dissimilarity analysis program COENOS (Jones 1978) of the B.C. Ministry of Environment and a similarity analysis program available at the Pacific Forestry Centre (Stanek et al. 1981) were used to help group vegetation types. Both programs employed a clustering procedure for species presence or absence and plant cover data.

3 RESULTS

Forty-nine slides and their surrounds were examined (Appendix 1, Fig. 5). One apparent slide (Deena-3, see Appendix 1) was later determined to be the result of yarding disturbance rather than mass wasting. Only data from its surround were used in subsequent analyses.

3.1 Surface Conditions of Slides and Adjacent Non-Slide Surrounds

The average open-face slide was 454 (84-1072) m in slope length, 59 (14-274) m in width, and the average area was 2.3 (0.1-15.5) ha. One torrent ran for more than 2400 m. In general, the failures left a chaotic, varied mixture of tree boles or logs, rocks, and soil.

Assuming an estimated average depth of 1.5 m for soils indicated by probing as being over 1 m deep, depths to bedrock or to a layer otherwise

impenetrable to the probe were significantly less in the upper and middle thirds of slides than in the lower slide or any part of the surround (Table 1). No differences in average depth occurred between any of the slope positions in the surround. Slope gradients decreased significantly from top to bottom of the slides and surrounding terrain (Table 1). Both upper and middle slide segments were significantly steeper than their equivalent surrounding terrain (Table 1). The mean gradient of the lower slope of slides in the CWHg2 (montane variant) was 46% as compared with 29% for the CWHg1 (submontane variant) and 31% for the CCPH zone. Unlike the CWHg1, there was no significant difference between the gradient of lower and middle thirds (46 vs. 54%) in the CWHg2. Bedrock exposure on the slides was significantly higher in the middle and upper slope positions than in the lower (Table 1).

The upper third of slides was judged to be more convex and drier than the middle and lower portions but differences were not significant. The same pattern existed in the non-slide surround. Logged terrain was rated as significantly more moist than slide surfaces.

The percentage of rotting logs was significantly greater in old-growth stands than in either logged stands or on slides (Table 2). Logged stands had a significantly higher rotting log cover than slides. A greater cover of rotting logs was present on lower than upper slope positions of old-growth (21 vs. 13%), logged (11 vs. 4%) and slide (6 vs. 2%) surfaces. The cover of rotting logs on slides generally increased from 0 for the 1- to 3-year class, to 8% for the 30- to 79-year class but decreased to 6% for the >80-year class.

FIGURE 5. Locations of landslide study areas on the Queen Charlotte Islands.

TABLE 1. Slope, soil depth, and bedrock exposure by slope position for slides and adjacent surround

State	Position[a]	Slope	Soil depth	Bedrock exposure
		%	cm	%
Slide	U	[b]68 a	50 b	8 a
	M	53 b	60 b	10 a
	L	33 d	92 a	2 b
Surround	U	58 b	93 a	1 b
	M	46 c	106 a	1 b
	L	32 d	110 a	<1 b

[a] U=Upper; M=Middle; L=Lower.

[b] Means within columns followed by the same letter are not significantly different at the 0.05 level (Student-Newman-Keuls' Multiple Range Test).

TABLE 2. Cover of natural (rotting) logs and recent slash on slide and surround surfaces

State	Natural (rotting) logs	Slash[a]	
		Fine	Coarse
	% cover		
Old growth	[b]16 a	3 b	4 b
Logged	8 b	8 a	22 a
Slide	4 c	2 b	8 b
Torrent	0 c	0 b	17 a

[a] Slash from recent logging, windthrow, or breakage. Fine = <5 cm diameter; coarse = >5 cm diameter.

[b] Means within columns followed by the same letter are not significantly different at the 0.05 level (Student-Newman-Keuls' Multiple Range Test).

Slash cover was significantly higher in logged stands than in old growth or on slides (Table 2). Fine (<5 cm diameter) slash decreased in cover with increasing age on both slide and logged areas. A similar relationship was not clear for coarse slash except that the lowest cover occurred in the oldest age classes for both slide and logged areas.

The surface cover of exposed mineral soil or bedrock decreased exponentially with increasing age of slides (Fig. 6). The lower portions of the slides accumulated an organic mat at a rate significantly faster than the middle or upper portions (Fig. 6). Accumulation rates of surface organic matter were relatively low on slides associated with the coarse conglomerate rock type and high on the fine sedimentary type or mixtures of this with other rock types.

Combining the 1- to 3-year (two transects) with the 4- to 14-year (40 transects) age classes of logged areas, the cover of exposed soil and bedrock averaged 14%. In older logged stands soil exposure was about 5%, a value similar to that recorded for old growth (Table 3). Soil exposure in recently logged stands was caused mainly by yarding activities and in old-growth stands by root overturns and surface runoff.

For slides, deep (>10 cm) humus increased from 1% cover on those 1 to 3 years old to 22% in the over 80-year class (Table 4). This range compared with an average of 54% for logged areas with no trends with age and 62% in old-growth stands. Deep humus was predominant on logged and old-growth areas and shallow humus was dominant on slides.

Logged surfaces had proportionally a much higher cover of rotten wood or mixtures of rotten wood and humified (FH) material than slides (Tables 3 and 4). Particularly in the oldest age classes, slide surfaces were covered more often with an H(Ah) layer, indicating a greater degree of mixing of organic and mineral particles on slides (Tables 3 and 4). Slides also had a considerable portion of their surfaces covered with a leaf litter lying directly on mineral soil. The percentage cover of this "litter only" category on slides reached a maximum in the 15- to 29-year class and was present only rarely in the youngest and oldest age classes (Table 4). The percentage of other surfaces such as stumps, roots, and large slash was considerably greater on logged areas than on slides (Tables 3 and 4).

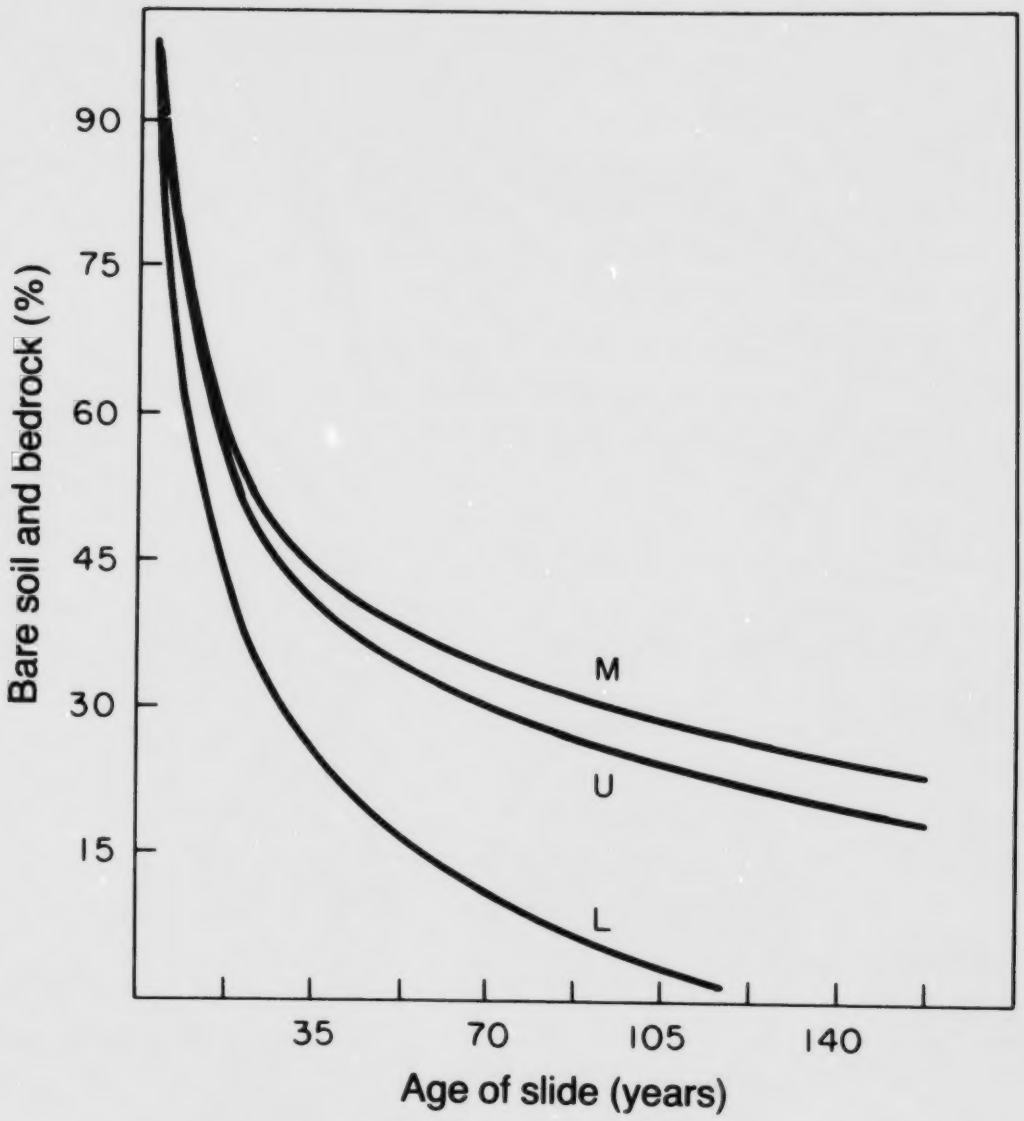

FIGURE 6. Percentage cover of exposed soil and bedrock as a function of slide age and slope position (U=Upper; M=Middle; L=Lower). R^2: U=0.53; M=0.47; L=0.86.

TABLE 3. Types of organic surface horizons by age class of logged areas and for old-growth stands

Age class	Mean age	Surface[a] MSE	H+	H-	R+	R-	Mix+	Mix-	H(Ah)+	H(Ah)-	L only	Other surfaces
						%						
1- 3	1	0 ab	[b]25 ab	23 a	10 ab	10 a	20 a	3 a	0 a	0 a	3 a	6 a
4-14	8	15 a	25 b	15 a	11 ab	3 a	15 a	2 a	2 a	2 a	1 a	9 a
15-29	23	5 a	22 b	13 a	16 a	8 a	15 a	3 a	0 a	8 a	1 a	8 a
30-55	41	4 a	43 a	27 a	4 b	0 a	8 a	2 a	0 a	1 a	1 a	9 a
Old growth		6 a	42 a	21 a	5 b	3 a	14 a	1 a	1 a	2 a	1 a	4 a

[a] MSE = Mineral soil or bedrock exposure; H = Humified material (FH); R = Rotten wood; Mix = Mixture of H and R; H(Ah) = Organic matter with mineral soil incorporated; + = >10 cm thick; - = <10 cm thick; L = Litter; Other surfaces = Stumps, tree boles, large slash.

[b] Means within columns followed by the same letter are not significantly different at the 0.05 level (Student-Newman-Keuls' Multiple Range Test).

TABLE 4. Types of organic surface horizons by age class of slides

Age class	Mean age	Surface[a] MSE	H+	H-	R+	R-	Mix+	Mix-	H(Ah)+	H(Ah)-	L only	Other surfaces
		%										
1- 3	2	[b]95 a	1 c	1 c	0 a	1 a	0 b	<1 a	<1 a	1 b	0 c	1 a
4-14	9	71 a	3 bc	8 c	<1 a	<1 a	1 ab	1 a	1 a	4 b	9 b	3 a
15-29	23	44 b	3 bc	21 b	0 a	3 a	<1 ab	2 a	2 a	6 b	17 a	2 a
30-79	52	34 b	8 ab	18 b	2 a	2 a	1 ab	<1 a	6 a	23 a	5 bc	2 a
80+	107	12 c	12 a	34 a	<1 a	1 a	4 a	2 a	6 a	27 a	1 c	2 a

[a] MSE = Mineral soil or bedrock exposed; H = Humified material (FH); R = Rotten wood; Mix = Mixture of H and R; H(Ah) = Organic matter with mineral soil incorporated; + = >10 cm thick; - = <10 cm thick; L = Litter; Other surfaces = Stumps, tree boles, large slash.

[b] Means within columns followed by the same letter are not significantly different at the 0.05 level (Student Newman-Keuls' Multiple Range Test).

3.2 Soil Features

Unlike the transect survey which systematically sampled each of the three slope positions of the slides and surrounds, data from the analyses of soil pits represent only the middle portions of slides and surrounds.

3.2.1 Surface organic layer

Considering only those slides with a surface organic layer sufficiently distinct to allow collection of a clean sample, trends in some properties occurred with age and differences were noted between slide and surround (logged or old-growth). The pH of humus decreased significantly and organic carbon and total nitrogen contents increased significantly with increasing slide age (Figs. 7 and 8). Significantly deeper layers of surface organic material occurred in the surround than on slides (Table 5). Values of pH for humus were significantly higher on slides than in the surround for 1- to 29-year-old slides. Differences were not significant for older slides. The percentage of organic carbon was significantly less for slide humus than in the surround for 1- to 29- and 30- to 79-year-old slides. In contrast, the average carbon content of humus in slides over 80 years of age was similar to that in the surround. Total nitrogen content was significantly lower on slides in the 1- to 29-year age class, equal to the surround in the 30- to 79-year class and significantly higher for slides over 80 years of age. Ratios of C:N were generally lower on slides than surrounds but significantly so only for the 30- to 79-year class (Table 5).

Characteristics of the surface organic horizons were not significantly correlated with the type of associated rock or with biogeoclimatic zone.

3.2.2 Mineral soil

Soils on slides were significantly warmer in the summer than soils in logged and old-growth surrounds: 11.4 vs. 9.6°C at 10 cm and 9.4 vs. 7.8°C at 50 cm.

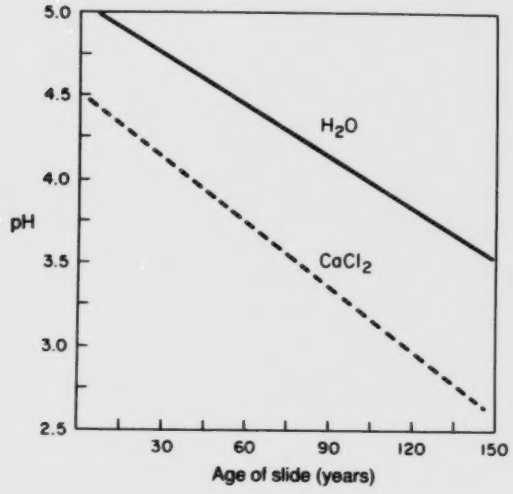

FIGURE 7. Acidity of surface organic layers as a function of slide age (pH measured in H_2O and 0.01 M $CaCl_2$). R^2: H_2O =0.27; $CaCl_2$ = 0.34.

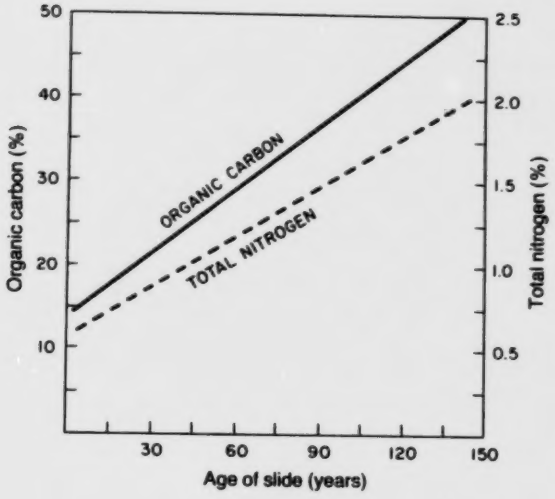

FIGURE 8. Organic carbon and total nitrogen concentrations of surface organic layers as a function of slide age. R^2: Carbon =0.65; Nitrogen = 0.58.

TABLE 5. Comparisons of several characteristics of surface organic horizons on slides (Sli.) with those on adjacent surrounds (Sur.)

Slide age class (yr)	Depth (cm)		pH (H_2O)		pH ($CaCl_2$)		Organic C (%)		Total N (%)		C:N ratio	
	Sli.	Sur.	Sli.	Sur.	Sli.	Sur.	Sli.	Sur.	Sli.	Sur.	Sli.	Sur.
1 - 29	[a]4 b	16 a	5.0 a	3.9 b	4.5 a	3.2 b	18 b	36 a	0.7 b	1.1 a	28 a	33 a
30 - 79	6 b	19 a	4.5 a	4.2 a	3.8 a	3.5 a	25 b	41 a	1.1 a	1.2 a	24 b	36 a
80+	6 b	16 a	4.0 a	4.0 a	3.2 a	3.1 a	42 a	41 a	1.6 a	1.1 b	27 a	37 a

[a] Means within age class/surface organic horizon characteristic pairings followed by the same letter are not significantly different at the 0.05 level (Student-Newman-Keuls' Multiple Range Test).

Soil materials were generally high in gravel (0.2-7.5 cm) and cobble (7.5-25.0 cm) content with a few sites high in stones (>25.0 cm). The average coarse fragment content by volume as estimated visually on the soil pit walls was 45% for slides and 39% for undisturbed surrounds. Differences between slide and surround were only marked in the upper 30 cm of the profiles with slide soils containing about 10% greater volume of coarse fragments in that portion than the undisturbed (Fig. 9). By weight, the average content of coarse fragments less than about 2 cm diameter of slide and undisturbed soils was 52 and 51%, respectively. Again, however, the slide soils exceeded the undisturbed soils in coarse fragment content by about 10% in the upper 30 cm of the profiles (Fig. 10).

Based on samples taken from horizons located at depths ranging from the mineral soil surface to as deep as 110 cm, average particle size distribution of the fraction <2 mm was 10.1, 25.5, and 64.4% for slides and 9.9, 26.4, and 63.9% for surrounds for clay, silt, and sand, respectively. Although essentially no average difference existed between

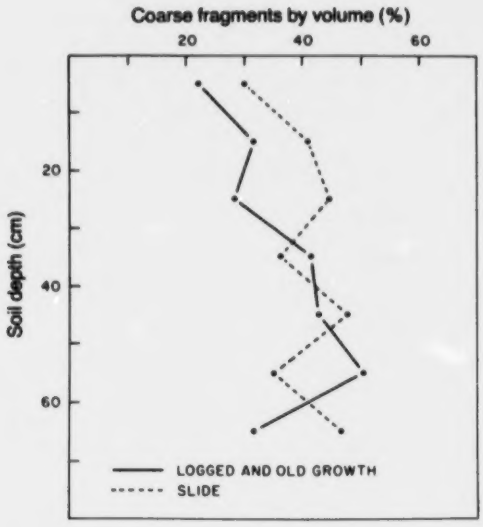

FIGURE 9. Percentage coarse fragments (>2 mm) by visual, volume estimate for mid-slide and undisturbed soils as a function of soil depth.

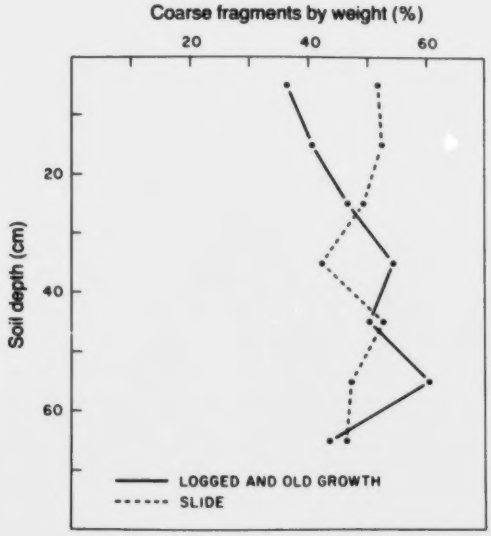

FIGURE 10. Percentage coarse fragments (2 mm to ca. 20 mm) by weight of collected samples for mid-slide and undisturbed soils as a function of soil depth.

slide and adjacent surround, there were differences in particle size distribution with depth (Fig. 11). Slide soils had lower clay and silt percentages and higher sand percentages in the upper 30 cm than undisturbed soils. In a less marked fashion, the reverse held below 30 cm.

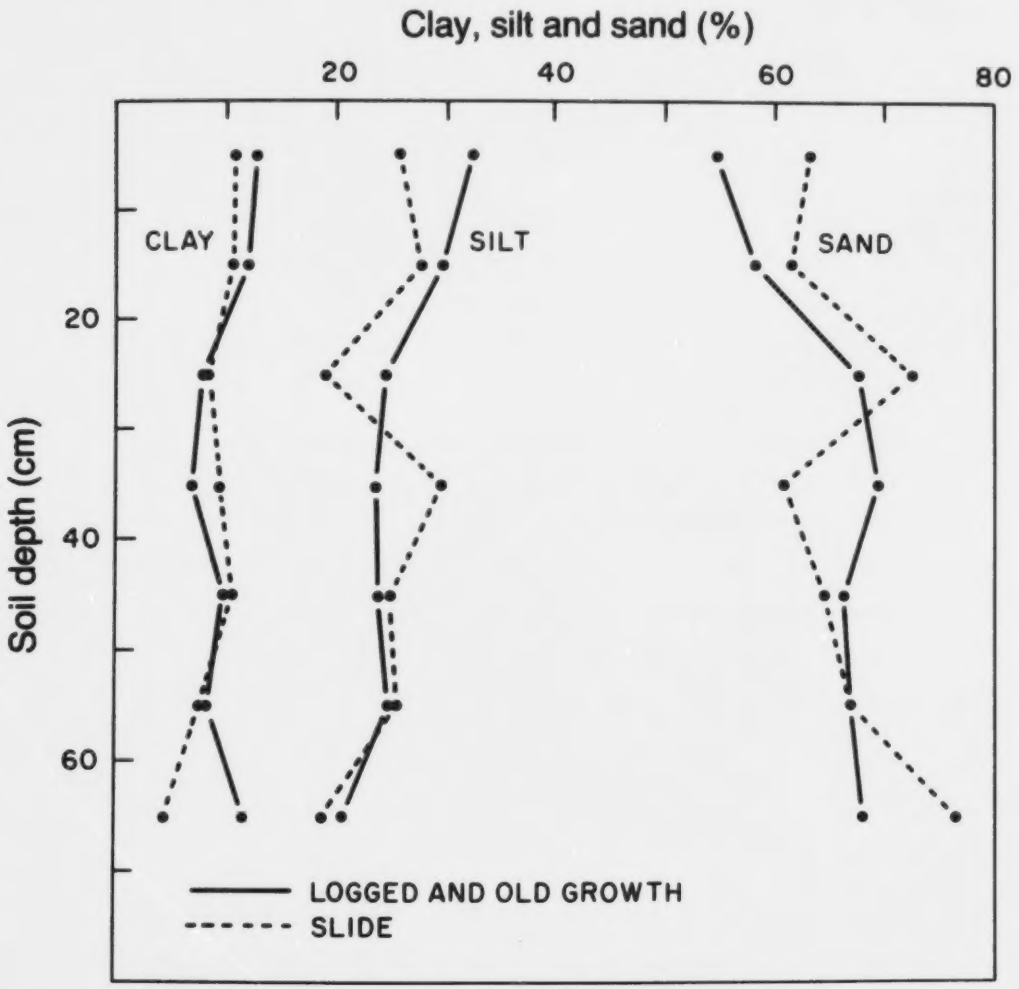

FIGURE 11. Percentage sand, silt, and clay in the mineral soil fraction (<2 mm) of collected samples for mid-slide and undisturbed soils as a function of soil depth.

Soils associated with fine sedimentary and calcareous rock types were high in clay content and those associated with granitic and hard volcanic bedrock were low in clay (Table 6). Soils associated with hard volcanics were significantly higher in silt content than granitic soils. Soils associated with fine sedimentary rock were low in sand content whereas those associated with granite were high in sand. The silt/clay ratio was particularly high in soils associated with hard volcanics and low in soils from coarse conglomerate and calcareous rock types (Table 6).

TABLE 6. Mean particle size distribution of the fraction less than 2 mm on the basis of rock type for mid-slide and undisturbed surround combined

Fraction	Rock type[a]						
	GR	CC	HV	SV	CA	FS	MX
	- - - - - - - - - - - - - - - % - - - - - - - - - - - - -						
Clay	[b]7.2 b	10.4 ab	7.2 b	9.9 ab	12.1 a	13.4 a	11.3 ab
Silt	22.9 b	26.5 ab	30.3 a	25.0 ab	23.8 ab	29.3 ab	27.9 ab
Sand	69.9 a	63.1 ab	62.5 ab	65.1 ab	64.1 ab	57.3 b	60.8 ab
Silt/Clay	6.0 ab	2.8 c	6.6 a	3.4 abc	2.6 c	3.3 abc	3.3 abc

[a] GR = Granitic; CC = Coarse conglomerate; HV = Hard volcanic; SV = Soft volcanic; CA = Calcareous; FS = Fine sedimentary; MX = Mixture.

[b] Means within rows followed by the same letter are not significantly different at the 0.05 level (Student-Newman-Keuls' Multiple Range Test).

The average pH of mineral soil was generally greater in slide soils (avg. = 5.3) than in the surround (avg. = 4.9) for the upper 60 cm of the profiles (Fig. 12). Soils associated with the coarse conglomerate type were particularly acid, especially in the undisturbed state (Table 7). Contrary to expectation, soils associated with calcareous and fine sedimentary rock types and mixtures were not any less acid than soils from granitics and volcanics. Unlike surface organic horizons, the mineral soil showed no definite trend in decreasing pH with increasing slide age.

TABLE 7. Mean pH for mid-slide and undisturbed mineral soil on the basis of rock type

	Rock type[a]						
State	GR	CC	HV	SV	CA	FS	MX
Slide	[b]5.4 a	5.0 a	5.5 a	5.3 a	5.4 a	5.1 a	4.9 a
Undisturbed	5.2 a	4.4 b	5.1 a	4.9 a	4.9 a	4.8 ab	5.2 a
All	5.3 a	4.7 b	5.3 a	5.1 a	5.1 a	4.9 ab	5.1 ab

[a] GR = Granitic; CC = Coarse conglomerate; HV = Hard volcanic; SV = Soft volcanic; CA = Calcareous; FS = Fine sedimentary; MX = Mixture.

[b] Within rows, means followed by the same letter are not significantly different at the 0.05 level (Student-Newman-Keuls' Multiple Range Test).

Average percentages of organic carbon and total nitrogen decreased with depth from about 8 to 5% for carbon and 0.4 to 0.2% for nitrogen in both slide and surround mineral soil. Percentages of organic carbon for the logged surround were higher than for old-growth and slide except at the extreme top and bottom of the sampled profiles. Nitrogen content was generally higher for both slide and logged than for old-growth soils except at the upper and lower extremes of the profiles. Ratios of C:N were lower throughout most of the average profile for slides than for logged and old-growth surrounds. The average C:N ratio of old-growth mineral soils (29.9) was significantly higher than for both logged (26.5) and slide (24.1) soils. Organic carbon content and C:N ratio were significantly lower in soils associated with calcareous rock types than with some other rock types (Table 8).

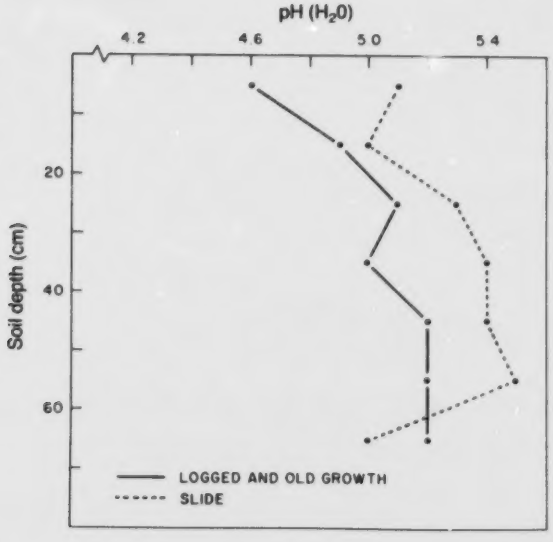

FIGURE. 12 Average pH (H_2O) for mid-slide and undisturbed mineral soils as a function of soil depth.

High organic carbon contents occurred in soils associated with hard volcanic and fine sedimentary rock types. The C:N ratio of coarse conglomerate soils was significantly higher than for soils derived from all other rock types (Table 8).

TABLE 8. Mean percentages of organic carbon and total nitrogen and C:N ratios for mid-slide, logged, and old-growth mineral soil as subdivided by rock type

State	Property	Rock type[a]						
		GR	CC	HV	SV	CA	FS	MX
		- - - - - - - - - - - - - - - - % - - - - - - - - - - - - - - - -						
Slide	% C	[b]5 a	7 a	8 a	6 a	4 a	7 a	8 a
Slide	% N	0.2 a	0.2 a	0.3 a	0.2a	0.2 a	0.3 a	0.3 a
Slide	C:N	22 b	32 a	23 b	24 b	22 b	25 b	22 b
Logged plus old growth	% C	8 ab	6 ab	8 ab	6 ab	4 b	10 a	6 ab
Logged plus old growth	% N	0.3 a	0.2 a	0.3 a	0.2 a	0.2 a	0.3 a	0.2 a
Logged	C:N	27 ab	33 a	23 ab	26 ab	24 ab	30 ab	21 b
Old growth	C:N	29 b	43 a	28 b	29 b	20 b	36 ab	31 ab
All	% C	6 ab	7 ab	8 a	6 ab	4 b	8 a	6 ab
All	% N	0.2 a	0.2 a	0.3 a	0.2 a	0.2 a	0.3 a	0.3 a
All	C:N	26 bc	34 a	24 bc	25 bc	22 c	29 b	24 bc

[a] GR = Granitic; CC = Coarse conglomerate; HV = Hard volcanic; SV = Soft volcanic; CA = Calcareous; FS = Fine sedimentary; MX = Mixture.

[b] Within rows, means followed by the same letter are not significantly different at the 0.05 level (Student-Newman-Keuls' Multiple Range Test).

3.2.3 Soil classification

The predominant soil group in logged and old-growth stands was the Ferro-Humic Podzol (U.S. classification = Humic Cryorthod) within which 65% of the profiles were classified. Of this, 74% were in the Orthic subgroup, 23% in the gleyed subgroup, and one profile was a Placic Ferro-Humic Podzol. The second most common soil group was the Humo-Ferric Podzol (Typic Cryorthod) within which 25% of the profiles were classified (50% Gleyed and 50% Orthic). The remainder were Humic Podzols (Humods), Dystric Brunisols (Dystrochrepts), and Folisols (Folists). As indicated by buried H horizons, about 15% of the profiles in logged and old-growth stands included profiles altered by previous mass wasting events.

Because of the extreme perturbation, soils on slides were extremely varied in morphology, resulting in 28 separate classifications or combinations of classifications at the subgroup level. Of the 44 slide profiles sampled, 15 involved truncated and buried (avg. depth of burial = 28 cm) pre-mass wasting soils and profiles with post-mass wasting erosional overlays (avg. = 12 cm deep). In addition, buried H horizons were noted within the pre-mass wasting portion of two profiles. Despite the perturbation, only 23% of the slide profiles were classified in the Regosol group (Entisols) with the remainder largely composed of perturbated Podzols (64%) and Dystric Brunisols (9%). Of the Podzols, the Ferro-Humic Podzols dominated (57%), Humo-Ferric Podzols were second most common (32%), and the remainder were Humic Podzols.

With increasing age class of slide, the proportion of Podzols increased and that of Regosols decreased (Fig. 13). Regosols did not occur in the oldest age class of slides or in the logged and old-growth stands.

3.3 Vegetation Development

3.3.1 General vegetative cover

Over 180 plant species were recorded (Appendix 2). The average total vegetative cover on all slides was 48%. Higher average covers occurred in the lower slope position than the upper (Fig. 14). Total vegetative cover averaged 63% on logged areas and 81% in old-growth stands with no significant differences among slope positions (Table 9). Logged areas had more vegetative cover than slide areas of similar age (Fig. 15). At 40 years of age, for instance, the average vegetative cover was 64% on slides and 94% on logged areas.

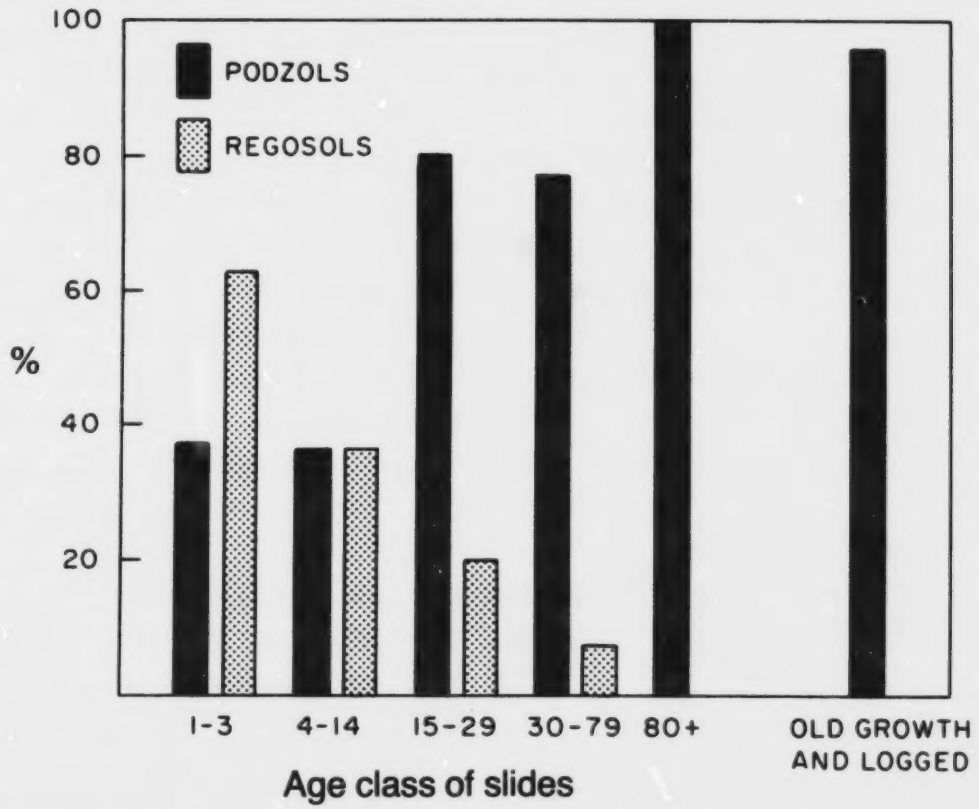

FIGURE 13. Proportions of podzols versus regosols with increasing time since landslide and a comparison with logged and old-growth surrounds.

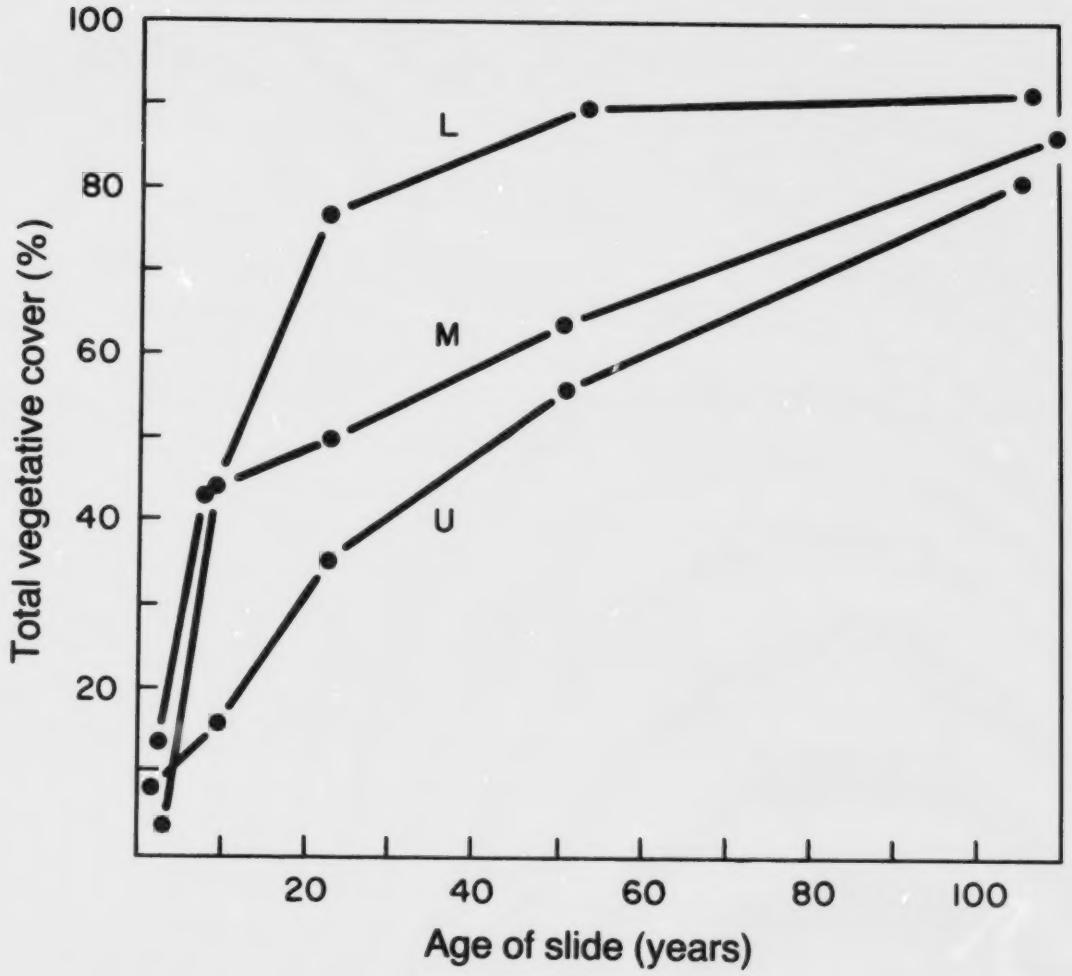

FIGURE 14. Total vegetative cover on slides as a function of age and slope position (U=Upper; M=Middle; L=Lower). Plotted points are averages of stands within each age class.

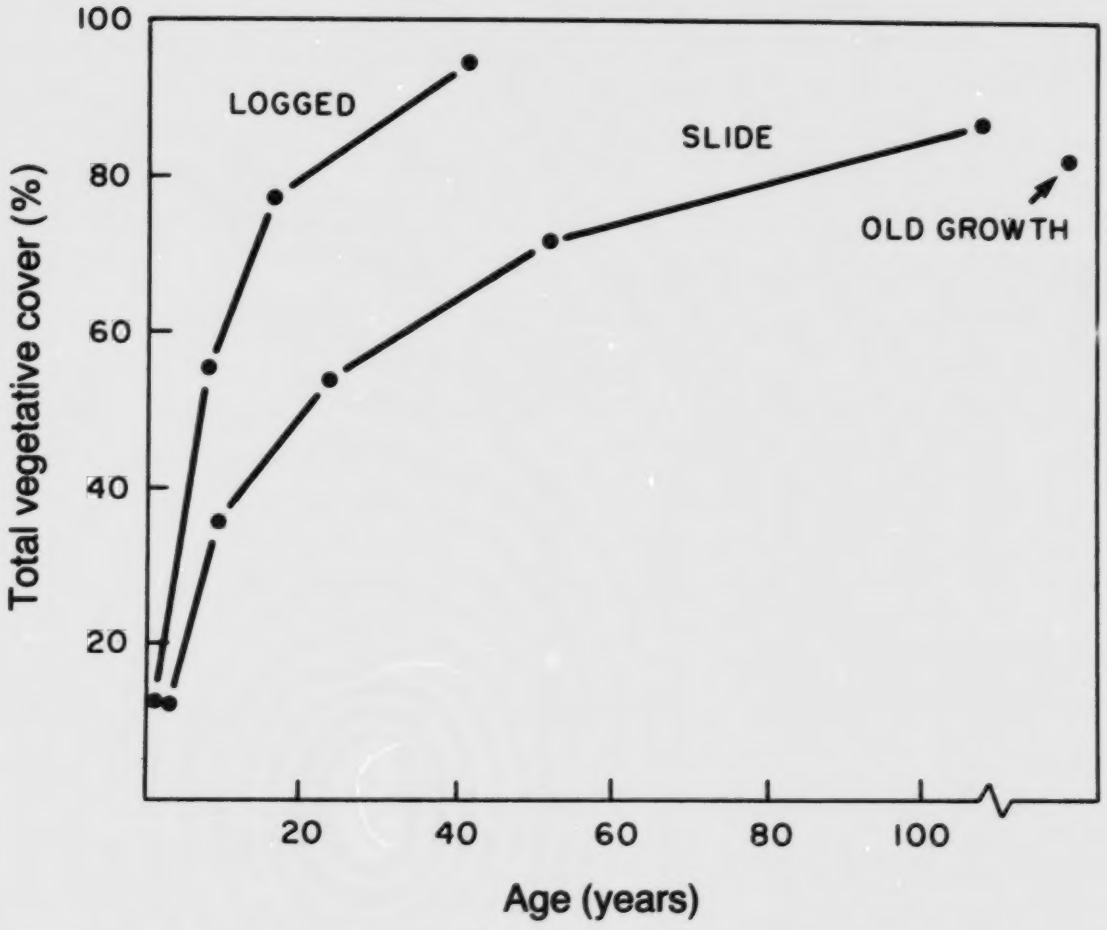

FIGURE 15. Total vegetative cover as a function of age for slides and logged areas. Plotted points are averages of stands within each age class.

TABLE 9. Total vegetative cover for upper, middle, and lower slope positions for slide, logged, and old-growth plots

Slope position	State		
	Slide	Logged	Old growth
	- - - - - - - - % - - - - - - - - -		
Upper	[a]37 b	63 a	80 a
Middle	49 ab	64 a	82 a
Lower	63 a	62 a	82 a

[a] Within columns, means followed by the same letter are not significantly different at the 0.05 level (Student-Newman-Keuls' Multiple Range Test).

Using covariance analyses to account for differences in average slide ages within rock types, the highest vegetative cover occurred on slides associated with fine sedimentary, calcareous, and mixture rock types and the lowest with coarse conglomerate and hard volcanic types (Table 10). Significantly lower cover of red alder (Alnus rubra) on slides occurred in association with coarse conglomerate and hard volcanic rock types than with calcareous, fine sedimentary, and mixture types. Western hemlock (Tsuga heterophylla) preferred granitic-associated slides, whereas Sitka spruce (Picea sitchensis) had significantly greater cover on slides associated with the fine sedimentary rock type (Table 10, Fig. 16).

Expressing cover values as ratios of one species to another gave additional insights to the soil preferences of deciduous and coniferous tree species. On this basis, rock types fell into two groups. One composed of granitic, coarse conglomerate, and hard volcanic types had alder:conifer cover ratios ranging from 0.1 to 0.3, alder:hemlock ratios from 0.2 to 0.8, and Sitka spruce:hemlock ratios from 0.4 to 1.3. The other group (soft volcanic, calcareous, fine sedimentary, and mixtures) had consistently higher ratios: alder:conifer (range 0.8 to 1.8); alder:hemlock (range 2.4 to 12.2); and Sitka spruce:hemlock (range 1.6-5.4).

The relationships noted between cover and rock type on slides were not as evident on logged areas (Table 11), and in old-growth stands they were rare (Table 12). Logged stands associated with fine sedimentary rock had an especially high cover of red alder and low conifer cover. High conifer cover on logged areas was associated with coarse conglomerate rock and high western redcedar cover with hard volcanics (Table 11).

TABLE 10. Total cover of vegetation, red alder, western hemlock, Sitka spruce, western redcedar, and all conifers on slides for each associated rock type

Cover	Rock type[a]						
	GR	CC	HV	SV	CA	FS	MX
	- - - - - - - - - - - - - - - % - - - - - - - - - - -						
Total vegetation	[b]47 bc	32 c	39 c	45 bc	61 a	68 a	64 ab
Red alder	5 bc	2 c	4 c	16 ab	22 a	24 a	25 a
Western hemlock	21 a	8 b	5 b	2 b	2 b	10 b	6 b
Sitka spruce	8 b	7 b	6 b	8 b	10 b	22 a	9 b
Western redcedar	3 a	1 a	2 a	2 a	<1 a	0 a	1 a
Total conifer[c]	34 a	16 c	14 c	13 c	12 c	32 ab	20 bc

[a] GR = Granitic; CC = Coarse conglomerate; HV = Hard volcanic; SV = Soft volcanic; CA = Calcareous; FS = Fine sedimentary; MX = Mixture.

[b] Means are adjusted using age as a covariant. Within rows, means followed by the same letter are not significantly different at the 0.05 level (t-test matrix).

[c] Includes minor species.

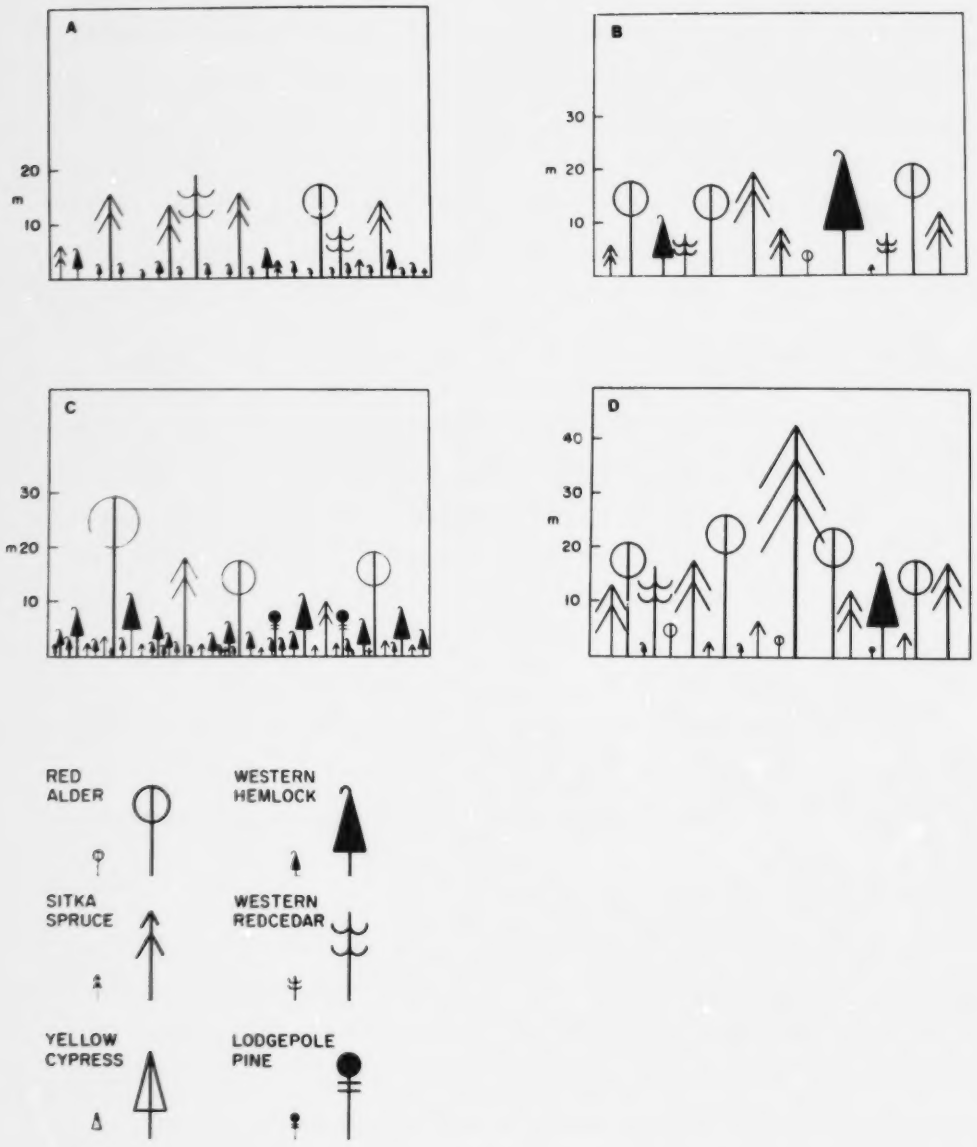

FIGURE 16. Average composition and structure of stands on slides 30-79 years of age: A. Upper slope, granitic, coarse conglomerate, and hard volcanic bedrock; B. Upper slope, fine sedimentary, calcareous, and soft volcanic bedrock; C. Lower slope, granitic, coarse conglomerate, and hard volcanic bedrock; D. Lower slope, fine sedimentary, calcareous, and soft volcanic bedrock.

The relationship of red alder cover with age of slides differed markedly from that of conifers (Figs. 17 and 18). Alder cover apparently increased rapidly to age 25, decreased sharply to age 50, and then decreased only slightly to 100 years (Fig. 17). In contrast, conifer cover increased from slide initiation to 100 years (Fig. 18). Total alder cover was highest in the lower slope position, intermediate in the middle, and least in the upper slope position, whereas conifer cover did not differ among slope positions (Figs. 17, 18, and 19A, B). In logged sites, red alder cover was high only in the lower slope position, but its overall average cover did not differ significantly between logged and slide areas (Fig. 19 C, D).

TABLE 11. Total cover of vegetation, red alder, western hemlock, Sitka spruce, western redcedar, and all conifers on logged areas for each associated rock type

Cover	Rock type[a]						
	GR	CC	HV	SV	CA	FS	MX
	- - - - - - - - - - - - - - - - % - - - - - - - - - - - - - - - -						
Total vegetation	[b]70 ab	65 ab	42 b	56 b	63 ab	90 a	59 ab
Red alder	14 b	1 c	2 bc	1 c	1 c	51 a	1 bc
Western hemlock	28 ab	35 a	9 b	14 b	24 ab	7 b	34 ab
Sitka spruce	4 a	9 a	6 a	9 a	8 a	5 a	2 a
Western redcedar	3 b	1 b	12 a	1 b	1 b	2 b	0 b
Total conifer[c]	35 ab	46 a	27 ab	23 b	33 ab	13 b	36 ab

[a] GR = Granitic; CC = Coarse conglomerate; HV = Hard volcanic; SV = Soft volcanic, CA = Calcareous; FS = Fine sedimentary; MX = Mixture.

[b] Means are adjusted using age as a covariant. Within rows, means followed by the same letter are not significantly different at the 0.05 level (t-test matrix).

[c] Includes minor species.

TABLE 12. Total cover of vegetation, red alder, western hemlock, Sitka spruce, western redcedar, and all conifers in old-growth stands for each associated rock type

Cover	Rock type[a]						
	GR	CC	HV	SV	CA	FS	MX
	- - - - - - - - - - - - - - - % - - - - - - - - - - - - - - -						
Total vegetation	[b]81 a	77 a	73 a	86 a	79 a	82 a	84 a
Red alder	0 a	<1 a	2 a	1 a	0 a	<1 a	<1 a
Western hemlock	43 a	52 a	29 a	37 a	45 a	45 a	25 a
Sitka spruce	19 a	0 a	5 a	8 a	7 a	1 a	4 a
Western redcedar	5 a	6 a	8 a	12 a	5 a	17 a	4 a
Yellow cypress	1 a	5 ab	1 b	3 ab	0 b	2 ab	9 a
Total conifer[c]	68 a	60 a	45 a	60 a	57 a	65 a	45 a

[a] GR = Granitic; CC = Coarse conglomerate; HV = Hard volcanic; SV = Soft volcanic; CA = Calcareous; FS = Fine sedimentary; MX = Mixture.

[b] Means are adjusted using age as a covariant. Within rows, means followed by the same letter are not significantly different at the 0.05 level (t=test matrix).

[c] Includes minor species.

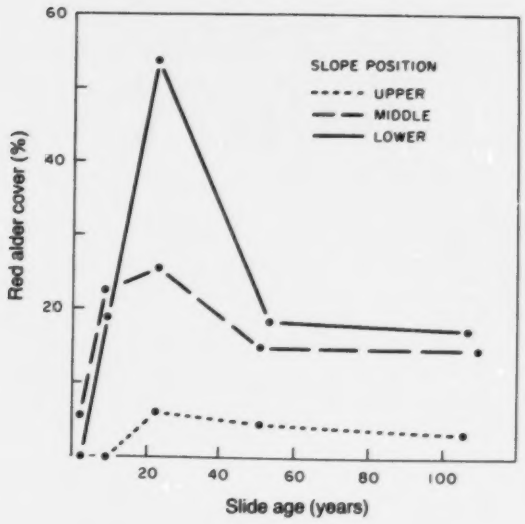

FIGURE 17. Cover of red alder on slides as a function of slide age and slope position. Plotted points are averages of stands within each age class.

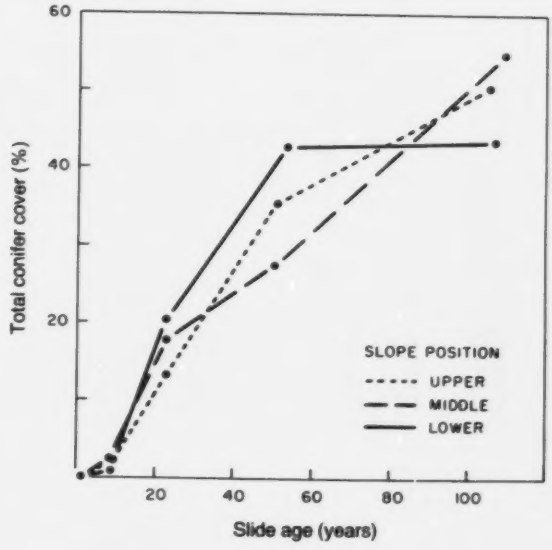

FIGURE 18. Total cover of conifers on slides as a function of slide age and slope position. Plotted points are averages of stands within each age class.

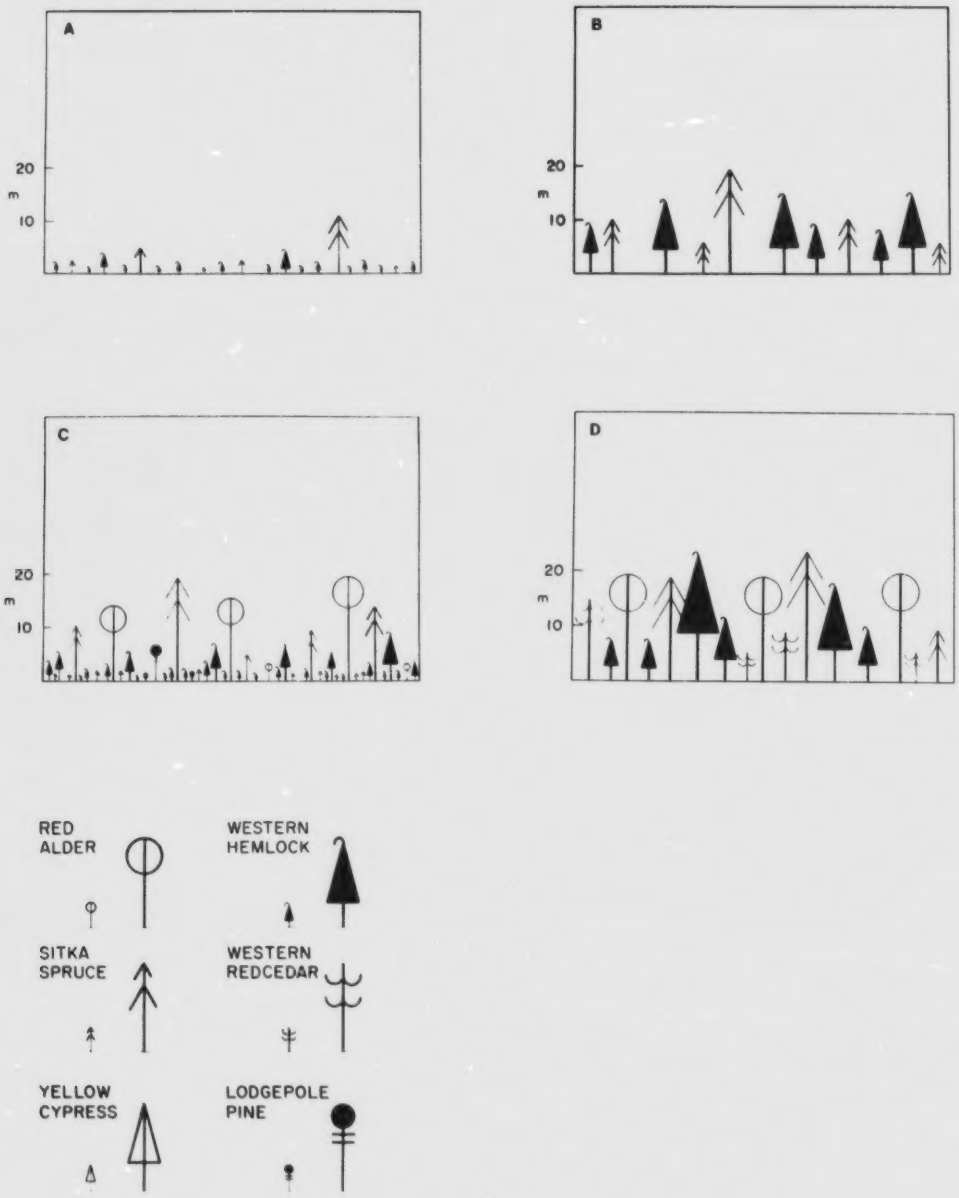

FIGURE 19. Average composition and structure of stands 30-59 years of age: A. Upper slope, slide; B. Upper slope, logged; C. Lower slope, slide; D. Lower slope, logged.

Shrub cover was generally low but was significantly higher on logged areas (9%) than on slides (3%), and was intermediate (5%) in old growth. Herb cover, also low, averaged 9% in old-growth stands and 8% in logged and slide areas. Up to 55 years of age, logged stands had higher bryophyte cover than slides, but cover on the latter subsequently increased rapidly with age class (Fig. 20). On slides over 80 years of age, average bryophyte cover exceeded that in old-growth stands (Fig. 20). For stands younger than 56 years (the maximum age of sampled logged stands), the average bryophyte cover was significantly higher for logged stands (26%) than for slides (12%).

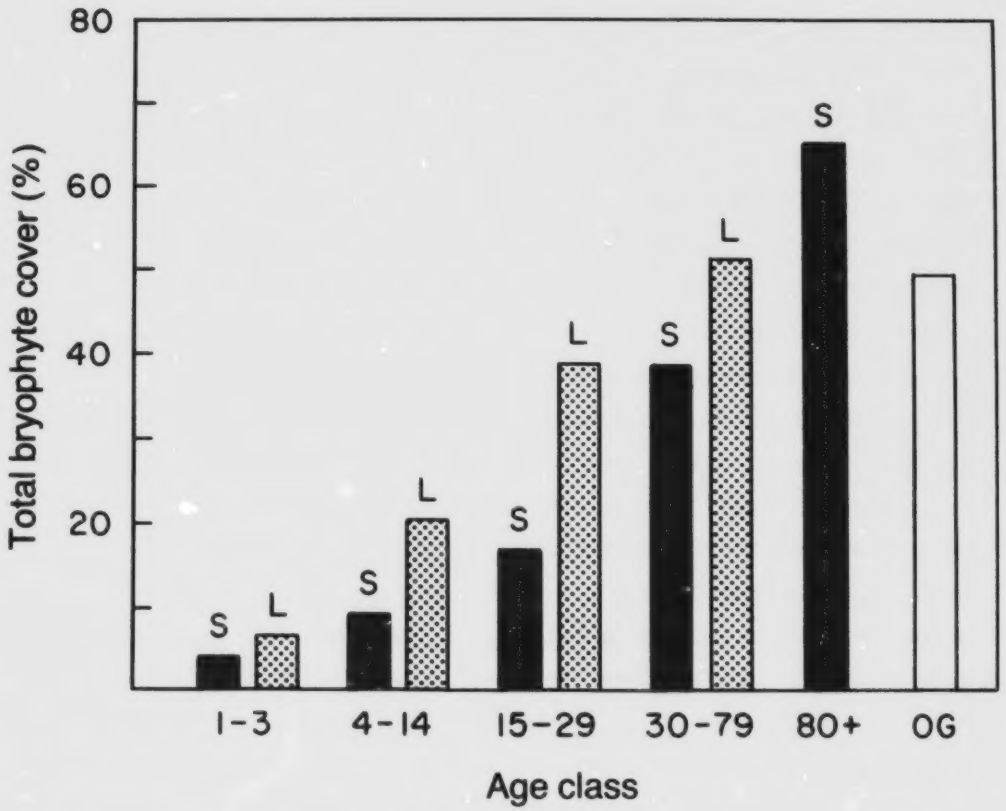

FIGURE 20. Bryophyte cover on slides (S), logged areas (L) and in old-growth stands (OG) as a function of age.

3.3.2 Deer browsing

Introduced Sitka deer (Odocoileus hemionus sitkensis Merriam) are found on all major islands in the Queen Charlottes (Cowan 1956) and are now numerous. Consequently, browsing of shrubs, herbs, and tree regeneration can be severe (Pojar and Banner 1984).

Browse utilization data were analyzed only for trees and shrubs less than 2 m in height, those available to deer, and only for those sufficiently frequent to allow valid comparisons.

Western hemlock was browsed significantly more on slides and logged areas and Sitka spruce more on slides than under old-growth stands (Table 13). Yellow cypress (Chamaecyparis nootkatensis) was browsed more heavily on slides than in logged areas or old-growth stands. Red alder and western redcedar (Thuja plicata) showed no significant browse utilization differences among states. Salmonberry (Rubus spectabilis) was browsed significantly more on slides and logged areas than in old growth (Table 13). No other differences among states were evident for other shrubs. Of herbs, only deer fern (Blechnum spicant) and sword fern (Polystichum munitum) were sufficiently frequent for comparisons between states. Deer fern was browsed significantly more on slides and sword fern more in logged areas than in old growth (Table 13).

On slides, western redcedar was browsed significantly more than western hemlock, Sitka spruce, and red alder (Table 14). Red alder was browsed significantly less than the other three species tested. Of the shrubs, huckleberries (Vaccinium spp.) were browsed significantly more than false azalea (Menziesia ferruginea). Of the herbs tested, wood-rush (Luzula parviflora) was browsed significantly less than all others. Deer fern was browsed significantly more than lady-fern (Athyrium filix-femina ssp. cyclosorum) and Merten's sedge (Carex mertensii) (Table 14).

On logged areas, western redcedar was significantly more browsed than Sitka spruce and western hemlock. No differences occurred among the shrubs tested and deer fern and sword fern were more severely browsed than lady-fern and Merten's sedge (Table 14).

TABLE 13. A comparison of mean browse ratings for major trees, shrubs, and herbs for slide, logged, and old-growth stands

State	Trees[a]					Shrubs[a]			Herbs[a]	
	Dr	Hw	Ss	Cw	Cy	Rs	Vspp	Mf	Bs	Pm
Slide	[b]0.8 a	1.4 a	1.4 a	2.4 a	3.5 a	2.7 a	2.7 a	2.0 a	1.6 a	1.3 ab
Logged	1.0 a	1.3 a	1.1ab	2.3 a	1.2 b	2.9 a	3.0 a	2.8 a	1.3 ab	1.7 a
Old growth	0.0 a	0.8 b	0.8 b	1.8 a	0.5 b	1.9 b	2.7 a	2.2 a	1.0 b	0.8 b

[a] Dr = Red alder; Hw = Western hemlock; Ss = Sitka spruce; Cw = Western redcedar; Cy = Yellow cypress; Rs = Salmonberry; Vspp = Huckleberry species (Vaccinium parvifolium, V. ovalifolium and V. alaskaense combined); Mf = False azalea; Bs = Deer fern; Pm = Sword fern.

[b] Within columns, means followed by the same letter are not significantly different at the 0.05 level (Duncan's Multiple Range Test).

TABLE 14. A comparison of mean browse ratings among species on slide, logged, and old-growth areas

Species	Group	Slide			Logged			Old growth		
		Rating[a]	1	2	Rating[a]	1	2	Rating[a]	1	2
Red alder	Tree	0.8	c	de	--	-	-	--	-	-
Western hemlock		1.4	b	cd	1.3	b	cd	0.8	a	c
Sitka spruce		1.4	b	cd	1.1	b	de	0.8	a	c
Western redcedar		2.4	a	ab	2.3	a	b	--	-	-
False azalea	Shrub	2.0	b	bc	2.8	a	a	2.2	a	b
Salmonberry		2.7	ab	a	2.9	a	a	--	-	-
Red elderberry		2.0	ab	abc	--	-	-	--	-	-
Huckleberry spp.		2.7	a	a	3.0	a	a	2.7	a	a
Lady fern	Herb	0.9	b	de	0.7	b	e	--	-	-
Deer fern		1.6	a	c	1.3	a	cd	1.0	a	c
Merten's sedge		0.9	b	de	--	-	-	--	-	-
Wood-rush		0.4	c	e	0.2	b	f	--	-	-
Sword fern		1.3	ab	cd	1.7	a	c	0.8	a	c

[a] 1 = Within columns and groups, means followed by the same letter are not significantly different at the 0.05 level (Duncan's Multiple Range Test).

2 = Within whole columns, means followed by the same letter are not significantly different at the 0.05 level (Duncan's Multiple Range Test).

In old-growth stands there were no differences in browse levels within groups of trees, shrubs, and herbs but in a comparison of all six species the two shrubs, false azalea and huckleberry, were significantly more browsed than the two tree and two herb species.

3.3.3 Tree stocking and composition by number of stems

Average stocking of tree regeneration in logged and slide stands was sufficient but variable (Table 15). Western hemlock predominated in all three states and western redcedar was relatively numerous on slides (Table 15). The average number of red alder stems was much less in the upper third of slides (700 per hectare) (Fig. 21) and logged surrounds (0 per hectare) than the middle (3300 per hectare) or lower thirds (4200 per hectare) of slides and the middle (1500 per hectare) or lower (1400 per hectare) thirds of logged stands. Western hemlock, the most common of the tree species, was over twice as numerous in the upper third of both slides and logged areas than in the middle or lower thirds. Red alder stems were 13 times more numerous on slides associated with calcareous rock types than on those associated with granitic rock types. Western hemlock stems were over 3 times as numerous on slides associated with granitic as those associated with calcareous rock.

The percentage composition of red alder, based on stems per hectare, was strongly associated with severely disturbed areas, i.e., slides (Table 16). Conversely, the western hemlock component was significantly greater in old-growth and logged stands than on slides (Table 16). Slides also featured high components of Sitka spruce and western redcedar relative to logged and old-growth stands (Table 16). When percentage composition was compared for tree species among slope positions and between logged and slide plots, significant differences occurred for western hemlock only. For this species, percentage composition was significantly higher for logged stands than for slides for each slope position. For slides, the percentage composition of western hemlock was significantly higher in the upper slope position than in the middle or lower positions.

TABLE 15. Stocking of major tree species for slide, logged, and old-growth stands

State	Species[a]				
	Dr	Hw	Ss	Cw	Cy
	Stems/ha[b]				
Slide	[c]3472 a	16116 b	4904 a	8394 a	1308 a
Logged	1069 b	20591 b	2966 a	1636 b	206 a
Old growth	12 b	70254 a	5939 a	3792 b	1053 a

[a] Dr = Red alder; Hw = Western hemlock; Ss = Sitka spruce; Cw = Western redcedar; Cy = Yellow cypress.
[b] All sizes.
[c] Within columns, means followed by the same letter are not significantly different at the 0.05 level (Student-Newman-Keuls' Multiple Range Test).

TABLE 16. Percentage composition of major tree species for slide, logged, and old-growth stands based on number of stems of all sizes

State	Species[a]				
	Dr	Hw	Ss	Cw	Cy
	%				
Slide	[b]16 a	37 b	18 a	24 a	3 a
Logged	7 b	71 a	13 ab	7 b	1 a
Old growth	<1 b	77 a	9 b	8 b	3 a

[a] Dr = Red alder; Hw = Western hemlock; Ss = Sitka spruce; Cw = Western redcedar; Cy = Yellow cypress.
[b] Within columns, means followed by the same letter are not significantly different at the 0.05 level (Student-Newman-Keuls' Multiple Range Test).

FIGURE 21. A 45-year-old slide with a sparse stocking of conifers in the upper portion (foreground) and a dense cover of red alder in the lower portion.

Because slide development could not be followed in this study over a period of time from initiation, the lag in establishment of trees could not be determined either in absolute terms or in relation to a particular stocking density. However, a comparison of mean average ages of sample trees with slide ages was considered useful in making a relative assessment of rapidity of colonization among species and slope positions. Considering all species and age classes, the average difference between mean sample tree age and slide age was significantly higher in the upper slope position (11 years) than in the middle or lower positions (7 years). The greatest difference occurred with red alder; the mean of 19 years difference for the upper slide was significantly higher than the 7 and 9 years for the middle and lower slope positions, respectively. No significant differences occurred among slope positions in age differences for western hemlock (9, 7, and 5 years) or Sitka spruce (10, 7, and 7 years) for upper, middle, and lower slide, respectively.

3.3.4 Tree composition by basal area

For all plots (variable or fixed) containing trees over 1.3 m in height, the composition of red alder based on basal area (cross-sectional area of tree stem at 1.3 m height) was significantly greater on slides than in logged or old-growth stands and greater in logged than in old-growth stands (Table 17). In contrast, western redcedar and yellow cypress made up a significantly higher proportion of old-growth stands than of slides or logged areas (Table 17). The proportion of total conifers based on basal area decreased significantly from old-growth to logged to slide areas (Table 17). A comparison of percentage tree composition based on basal area made between logged and slide plots only up to 55 years of age (the oldest logged plots studied) gave results similar to those in Table 17 except that the percentage composition of Sitka spruce was not significantly greater on slides than in logged stands.

TABLE 17. Percentage composition by basal area for major tree species for slide, logged, and old-growth stands

State	Species[a]					
	Dr	Hw	Ss	Cw	Cy	All conifers[b]
	- - - - - - - - - - - - % - - - - - - - - - - - - - - - - - -
Slide	[c]45 a	14 b	32 a	3 b	1 b	55 c
Logged	18 b	59 a	21 b	2 b	0 b	82 b
Old growth	1 c	48 a	12 b	28 a	10 a	99 a

[a] Dr = Red alder; Hw = Western hemlock; Ss = Sitka spruce; Cw = Western redcedar; Cy = Yellow cypress.

[b] Includes minor species.

[c] Within columns, means followed by the same letter are not significantly different at the 0.05 level (Student-Newman-Keuls' Multiple Range Test).

3.3.5 Vegetation groups

The COENOS and PFC vegetation analyses programs did not organize the vegetation plots into sufficiently homogeneous or distinct groups to allow direct correlations of plant groups with age and habitat factors. The analyses, however, did aid in a more subjective grouping based on dominant plants for each vegetation layer.

Although slides were sampled in both the CWHg and CCPH biogeoclimatic zones, differences in patterns of revegetation between these zones were not sufficiently major in the survey sample areas to warrant their separation. Minor differences are noted in the group descriptions, including differences between the CWHg1 (submontane) and CWHg2 (montane) variants.

Eight groups were described for slides and three groups were described for logged areas. A few unique plots on slides are discussed separately. Common species (those occurring in at least 40% of the plots in a group) are listed in Table 18. In some plots, poor site conditions, browsing by deer, and a lack of plant reproductive structures made separation of some species impossible.

Approximately 35% of the plants occurred in at least 5 of the 11 groups and many plants were common for both slides and logged stands. In addition, many of these species are also a conspicuous element of old-growth stands (Table 18).

1. Slide vegetation groups

Suggested relationships among the vegetation groups are illustrated in Figure 22. These relationships relate primarily to soil conditions and to stage of development.

Group 1. This group represents the earliest stage in the revegetation of landslides. The substrate is exposed bedrock or a mixture of rubble and mineral soil. Revegetation on bedrock proceeds slowly and is restricted to pockets of mineral soil located in crevices and shallow depressions. Mineral soil and rubble substrates are often unstable and plant colonization is retarded by continuous surficial erosion, especially on the upper slope position. Slides in the CWHg2 (montane) variant tended to be steep in the lower slope position also, and erosion of material from this position into creeks and ravines was common.

Debris such as logs, fallen trees, and stumps occasionally line the edges of slides or become stabilized on level benches or gentle slopes. Their presence permits plant colonization. Ridges between gullies generally become revegetated before gully bottoms. Plants also invade recent slides as clumps broken from eroding scarp faces come to rest on gentler terrain or become trapped by debris.

Total vegetative cover of the group varies from less than 1 to 11%, with the average cover higher in CWHg1 plots (3.5%) than CWHg2 (1.0%). The latter plots also had the lowest diversity of species.

TABLE 18. Number of plots, average age, average total vegetative cover, and common plant species for vegetation groups, older logged plots, and old-growth[a]

		Major vegetation groups															
		Slide								Logged			Older logged plots	Old-growth plots[a]			
		1	2	3	4	5	6	7	8	9	10	11		CWHg1	CWHg2	CCFH	All
No. of plots		44	10	10	9	26	11	6	12	20	27	6	7	12	10	26	48
Avg. age (slide or logging)		5	5	11	28	73	31	36	107	5	13	10	41	-	-	-	-
Avg. total cover		3	32	78	86	82	25	88	90	30	73	84	94	80	76	83	81
Species[b]	Layer[c]																
Alnus rubra	MC				X	X						X	X				
Picea sitchensis	MC								X				X				
Tsuga heterophylla	MC								X				X	X	X	X	X
Thuja plicata	MC														X		
Chamaecyparis nootkatensis	MC														X		
Picea sitchensis	A3					X											
Tsuga heterophylla	A3												X		X	X	
Alnus rubra	TS			X	X							X					
Picea sitchensis	TS				X			X					X				
Tsuga heterophylla	TS				X			X			X		X	X	X	X	X
Alnus rubra	LS		X	X													
Picea sitchensis	LS		X	X	X		X	X		X	X	X			X	X	X
Tsuga heterophylla	LS		X	X	X		X	X	X	X	X	X		X	X	X	X
Thuja plicata	LS		X	X	X		X	X			X						
Rubus spectabilis	S	X	X	X	X	X	X			X	X	X	X			X	
Vaccinium spp.	S		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Sambucus racemosa	S		X							X							
Gaultheria shallon	S							X					X				
Menziesia ferruginea	S									X	X		X		X	X	X
Blechnum spicant	H	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Luzula parviflora	H	X	X	X		X			X		X	X					
Epilobium spp.	H		X	X			X										

TABLE 18. Cont.

Species[b]	Layer[c]	Major vegetation groups: Slide 1	Slide 2	Slide 3	Slide 4	Slide 5	Slide 6	Slide 7	Slide 8	Logged 9	Logged 10	Logged 11	Older logged plots	Old-growth plots[a]: CWHg1	CWHg2	CCPH	All
Carex mertensii	H					X											
Polystichum spp.	H		X	X	X	X	X				X	X	X	X			
Cirsium vulgare	H		X	X													
Trisetum cernuum	H		X	X	X		X				X	X					
Senecio spp.	H		X														
Athyrium filix-femina	H		X	X	X	X					X	X	X				
Tolmiea menziesii	H		X														
Agrostis scabra	H			X			X										
Gymnocarpium dryopteris	H			X													
Galium triflorum	H			X	X							X					
Viola spp.	H				X		X										
Lycopodium clavatum	H							X									
Dryopteris assimilis	H								X			X					
Coptis asplenifolia	H									X	X	X			X	X	X
Maianthemum dilatatum	H									X	X						
Prenanthes alata	H											X					
Moneses uniflora	H													X			
Listera cordata	H													X	X	X	X
Streptopus amplexifolius	H														X		
Cornus unalaschkensis	H														X		
Listera caurina	H														X		
Lycopodium selago	H														X	X	
Polypodium vulgare	H														X		
Tiarella trifoliata	H														X		
Pogonatum contortum	B	X	X	X	X		X	X									
Polytrichum commune	B		X							X	X						
Pogonatum alpinum	B			X	X	X			X								
Rhytidiadelphus loreus	B		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Dicranum fuscescens	B		X		X		X		X	X	X	X	X	X	X	X	X

TABLE 18. Concluded

Species[b]	Layer[c]	Major vegetation groups: Slide 1	2	3	4	5	6	7	8	Logged 9	10	11	Older logged plots	Old-growth plots[a] CWHg1	CWHg2	CCPH	All
Pellia spp.	B		X	X	X				X			X			X	X	X
Hylocomium splendens	B			X					X	X	X		X	X	X	X	X
Stokesiella oregana	B			X	X	X		X	X	X	X		X	X	X	X	X
Conocephalum conicum	B			X								X					
Hypnum circinale	B				X				X		X		X		X	X	X
Rhacomitrium spp.	B				X		X										
Isopterygium elegans	B				X				X			X					
Plagiothecium undulatum	B				X	X		X	X	X	X	X	X	X	X	X	X
Scapania bolanderi	B				X	X	X	X	X	X	X		X	X	X	X	X
Rhizomnium glabrescens	B				X	X		X	X		X	X	X	X	X	X	X
Diplophyllum albicans	B				X		X								X	X	X
Plagiomnium insigne	B				X							X					
Leucolepis menziesii	B				X	X			X						X		
Hookeria lucens	B								X				X		X	X	X
Plagiochila asplenioides	B														X		
Dicranum scoparium	B														X	X	

[a] Common plant species are those which occur in at least 40% of the plots in a group. Vegetation groups are described in the text.

[b] Vaccinium spp. = V. alaskaense, V. ovalifolium, V. parvifolium; Epilobium spp. = E. delicatum, E. glandulosum; Polystichum spp. = P. lonchitis, P. munitum; Senecio spp. = S. sylvaticus, S. vulgaris; Viola spp. = V. glabella, unknown Viola spp.; Pellia spp. = unknown Pellia spp.; Rhacomitrium spp. = R. canescens, R. heterostichum.

[c] MC = Main tree canopy; A3 = Intermediate tree canopy; TS = Tall shrub (2-10m); LS = Low shrub (<2m); S = Shrub species (TS and LS); H = Herb; B = Bryophyte.

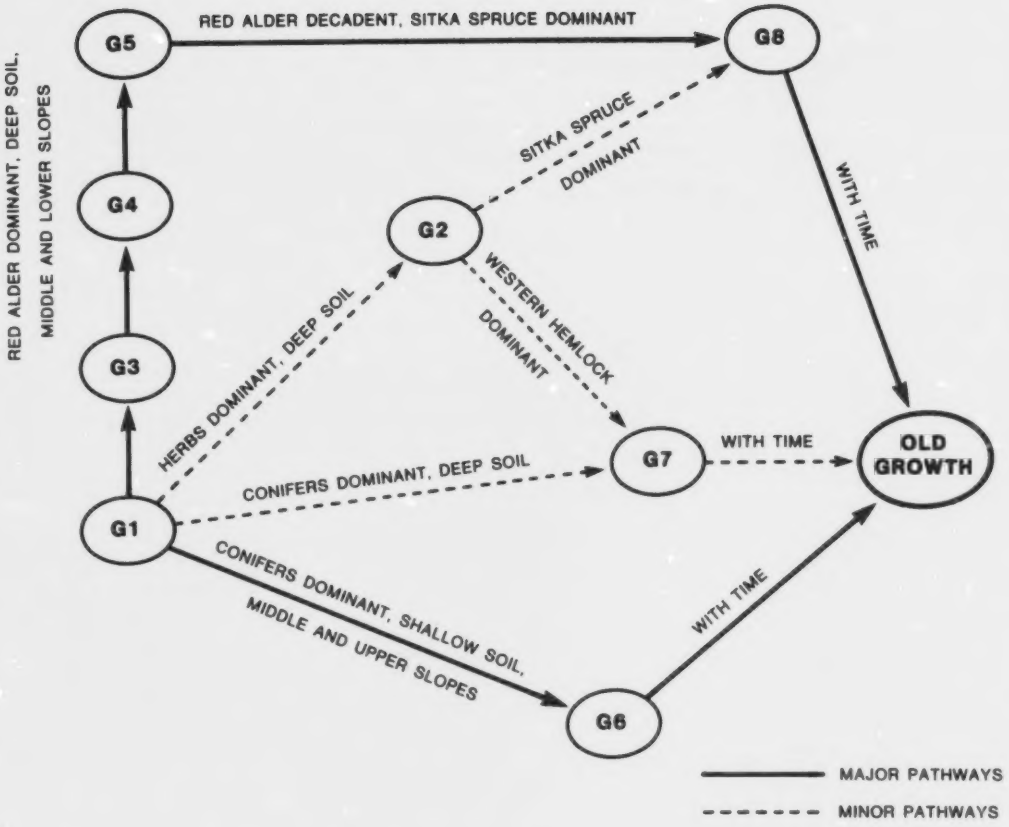

FIGURE 22. Relationships among the eight slide vegetation groups and old growth. G = Group.

Western redcedar, western hemlock, Sitka spruce and yellow cypress (CWHg2 and CCPH only) are occasionally present as low shrubs or seedlings with a cover of 1% or less. Rubus spectabilis is the only commonly occurring shrub species (Table 18). Most cover comes from herbs and bryophytes (1-2% each). Blechnum spicant and Luzula parviflora are common herbs. Carex mertensii, Epilobium spp. (E. delicatum and E. glandulosum), Athyrium filix-femina ssp. cyclosorum, Polystichum spp. (P. munitum and P. lonchitis), Senecio spp. (S. sylvaticus and S. vulgaris), and Tolmiea menziesii occur occasionally.

Bryophytes include those typically found on exposed mineral soil. Pogonatum contortum is common and P. alpinum and Polytrichum commune are occasionally present. In addition, Rhytidiadelphus loreus, Stokesiella oregana, and Dicranum fuscescens may be present on organic debris.

Most of the plots in this group were situated on slides less than 10 years of age. However, especially on steep, upper slopes, it may be several decades before an appreciable cover of vegetation is obtained. For instance, one plot in this group on a 38-year-old slide had a total vegetative cover of less than 1%.

Group 2. This group is representative of vegetation on a small number of plots sampled in both biogeoclimatic zones. It is characterized by a high cover of herbs and/or bryophytes on recently failed slopes with a relatively deep, stable mineral soil substrate. It may be present on a part of slides otherwise characterized by Group 1 or by a greater cover of red alder.

Total cover is variable but exceeds 16%. Red alder, western hemlock, Sitka spruce, and western redcedar (often severely browsed) are common tree species of the low shrub layer with a combined total cover of 5% or less. The shrubs Rubus spectabilis and Vaccinium spp. are common but are limited to a cover of 1% or less by deer browsing.

Cover of herbs and bryophytes is generally between 15 and 40%, each with intervening bare areas of bedrock and mixtures of rubble and mineral soil. Common herbs are Blechnum spicant, Polystichum spp., Cirsium vulgare, Epilobium spp., Trisetum cernuum, Luzula parviflora, Athyrium filix-femina ssp. cyclosorum, Tolmiea menziesii, and Senecio spp.

The cover of bryophytes includes Pogonatum contortum, Polytrichum commune, Rhytidiadelphus loreus, and Dicranum fuscescens. Pellia spp. are often present on moist, seepy microsites.

Group 3. This group, the first of three dominated by red alder, is characterized by an extensive cover of red alder in the tall or low shrub layers. It is found typically on middle and lower slopes in which the substrate of soil and rubble is stable and moist, and particularly when associated with fine sedimentary, calcareous, or soft volcanic bedrock. Representative vegetation of the group occurs on slides varying in age from 3 to 33 years of which the majority are less than 10 years of age.

The total vegetation cover is between 60 and 100% (31% in one plot with a high rubble cover). In general, red alder dominates and other plant species are suppressed and of low cover. Western hemlock, Sitka spruce, and western redcedar are present in the low shrub layer, often with a total combined cover of less than 5%.

The shrubs Rubus spectabilis and Vaccinium spp. are common but are maintained at a cover of less than 1% by severe browsing.

Herb cover varies between 1 and 20%. Plants are sparsely scattered underneath the dense alder or in patches in small openings. The most common species are Luzula parviflora, Blechnum spicant, Agrostis scabra, Cirsium vulgare, Polystichum spp., Gymnocarpium dryopteris, Epilobium spp., Galium triflorum, Trisetum cernuum, and Athyrium filix-femina ssp. cyclosorum.

Bryophyte cover is generally 3% or less. Species include many common to Groups 1 and 2 and to undisturbed forested areas, such as Hylocomium splendens, Pogonatum alpinum, P. contortum, Stokesiella oregana, Rhytidiadelphus loreus, Pellia spp., and Conocephalum conicum.

Group 4. As a later stage of Group 3, this group is represented by plots on slides 14-45 years of age. Total cover is 80-100% and is dominated by red alder at about 60% cover and 10 m in height. The number of stems per hectare is much reduced from the Group 3 stage. Sitka spruce usually dominates the understory tall shrub layer and on a few of the older slides equals or nearly equals the alder in height. Sitka spruce also occurs as a low shrub and its total cover in all layers may exceed 20%. Western hemlock is also common in the shrub layer but is usually shorter than the spruce. Western redcedar stems are fairly numerous but, as a result of browsing, total cover rarely exceeds 1%. In some areas of inexplicably light browsing pressure, Rubus spectabilis reaches more than 10% cover as a tall shrub. Along with Vaccinium spp., it is normally present only as a low shrub.

Herb cover varies between less than 1 and 25%. The most common species are Trisetum cernuum, Galium triflorum, Athyrium filix-femina ssp. cyclosorum, Polystichum spp., Viola spp., and Blechnum spicant. Species more characteristic of open exposure, such as Cirsium vulgare, Senecio spp., and Epilobium spp., occur much less frequently or are absent in this group.

Bryophyte cover is about 30% on most plots, considerably higher than in Group 3. Species are generally characteristic of non-slide, forested sites and include especially Rhytidiadelphus loreus and Stokesiella oregana. Other common species include Hypnum circinale, Dicranum fuscescens, Plagiothecium undulatum, Scapania bolanderi, Rhizomnium glabrescens, Pogonatum alpinum, Rhacomitrium spp. (R. canescens and R. heterostichum), Isopterygium elegans, Diplophyllum albicans, Plagiomnium insigne, Leucolepis menziesii, and Pellia spp.

Group 5. This group represents a large number of plots sampled on slides aged 60-102 years, primarily in the CCPH zone and CWHgl (submontane) variant. The vegetation is dominated by red alder in the main canopy where it has a cover of less than 50%. The decadent red alder is being supplanted in dominance by conifers released from the understory. Sitka spruce is common as a tall shrub or small tree just underneath the canopy of red alder. Its cover ranges from 10 to 40%. Western hemlock is often present but is usually shorter in height and lower in cover than the Sitka spruce. Western redcedar and occasionally yellow cypress (CCPH and CWHg2) are present as small trees or tall shrubs with a cover of 5-10%; these possibly became well established before deer browsing reached critical levels.

Severely browsed Rubus spectabilis and Vaccinium spp. are common shrubs but only reach 1% cover and are seldom over 2 m in height.

In general, herb cover is less than 5%. Common species include Polystichum spp., Athyrium filix-femina ssp. cyclosorum, Blechnum spicant, Carex mertensii, and Luzula parviflora. Polypodium vulgare ssp. occidentale is sometimes present as an epiphyte on red alder. Less common species include Tricetum cernuum, Stellaria crispa, and Dryopteris assimilis.

Bryophyte cover is variable but generally exceeds 60%. On some plots, species are confined to elevated positions off the forest floor on logs and the base of trees. The remaining forest floor is covered with leaf litter. Rhytidiadelphus loreus has the highest cover, with Pogonatum alpinum and Stokesiella oregana also often occurring in large patches. Other common species include Leucolepis menziezii, Rhizomnium glabrescens, Plagiothecium undulatum, and Scapania bolanderi. Conocephalum conicum and Pellia spp. are usually present on moist, seepy microsites.

Group 6. This group is represented by plots in the upper and middle slopes of slides 14-48 years of age. It is characterized by a low cover of conifers in the low and occasionally tall shrub layers.

The substrate of largely coarse rubble and bare bedrock keeps total plant cover low, i.e., less than 40% and confined to pockets of humus and mineral soil in small depressions and fissures in the bedrock surface. Red alder is not a component though it may be present on more suitable sites of the same slide.

Western hemlock or Sitka spruce are the dominant species but are usually less than 2 m in height. Lodgepole pine (Pinus contorta) is occasionally present with a height of less than 10 m. Deer browsing and poor site conditions keep western redcedar and yellow cypress to less than 1 m in height and 5% in cover. Sitka alder (Alnus sinuata) is occasionally present as a low shrub. Conifer seedlings are usually common.

The shrubs Rubus spectabilis and Vaccinium spp. are common and Gaultheria shallon and Menziesia ferruginea are occasional, but none exceed 2% in cover.

Herb cover is generally 5% or less. Agrostis scabra, Blechnum spicant, Epilobium sp., Polystichum spp., Viola spp., and Trisetum cernuum are the most common species. In addition, Lycopodium clavatum was common on CWHg2 variant plots and Galium triflorum, Lycopodium selago, Adiantum pedatum ssp. aleuticum, Carex mertensii, and Prenanthes alata were common in CCPH zone plots.

Bryophyte cover on most plots is 10% or less. Common species on rock and exposed mineral soil are Pogonatum contortum, Diplophyllum albicans, Rhacomitrium spp., and Dicranum fuscescens. Rhytidiadelphus loreus and Scapania bolanderi are commonly found underneath shrubs.

Group 7. Three landslides in the CWHg1 (submontane) variant developed a strictly conifer tree cover with no or insignificant numbers of red alder stems on all slope positions. The slides varied in age between 35 and 38 years.

Total vegetative cover usually exceeds 90%, mainly western hemlock (50% cover) in the tall or low shrub layers. Sitka spruce is less abundant, with a cover usually less than 20%. Western redcedar

is commonly present but does not exceed 1% cover or 2 m in height because of browsing pressure. Lodgepole pine is an unusual component of some plots in the shrub or tree layers.

Common shrubs are Gaultheria shallon and Vaccinium spp. They are confined to the low shrub layer and a total cover of less than 5%.

Herb cover does not exceed 2%. Blechnum spicant and Lycopodium clavatum are the only common species. L. selago, Epilobium spp., Listera cordata, and Trisetum cernuum occur occasionally.

Bryophyte cover varies between 2 and 45%. Common species are Rhytidiadelphus loreus, Scapania bolanderi, Pogonatum contortum, Rhizomnium glabrescens, and Stokesiella oregana. Occasional species include Plagiomnium insigne, Hylocomium splendens, Dicranum fuscescens, and Plagiothecium undulatum.

Group 8. This group is represented by plots on slides 48-155 years of age. It differs from Group 7 by a dominant cover (30-60%) of Sitka spruce and less (5-40%) of shorter western hemlock. Western redcedar and yellow cypress are occasionally present beneath the main canopy of Sitka spruce. Red alder is occasionally present and may in some cases have been present in greater abundance in earlier stages. In some stands, however, there is no indication of red alder ever being present.

Shrub species are low in cover. Vaccinium spp. are common and Rubus spectabilis is occasionally present.

Herb cover is 1% or less. Blechnum spicant, Dryopteris assimilis, and Luzula parviflora are common species.

Bryophyte cover is also 1% or less but often consists of a large number of species. Those which are common include Dicranum fuscescens, Hookeria lucens, Hypnum circinale, Hylocomium splendens, Isopterygium elegans, Leucolepis menziesii, Mnium glabrescens, Pellia spp., Plagiothecium undulatum, Pogonatum alpinum, Scapania bolanderi, and Stokesiella oregana.

2. Unique slides

Plots in a number of slides were difficult to fit into any of the foregoing groups. They are briefly described in the following section.

Kaisun 1 and 4. Vegetation on two of the three slides sampled on the exposed, salt-spray influenced west coast of Moresby Island appeared to be similar to the Spruce-Reedgrass ecosystem unit described by Banner et al. (1986) and Lewis (1982). Vegetation was dominated by a canopy of Sitka spruce and an understory of Calamagrostis nutkaensis.

Peel 1. The substrate on this slide was a mixture of bare bedrock, rubble, and shallow mineral soil. Total vegetation cover by plot varied from 24 to 48%. Trees and shrub species were similar to those common on other slides. Herb cover was high and consisted of several species rarely or never present on other slides, e.g., Adiantum pedatum ssp. aleuticum, Campanula alaskana, Carex anthoxanthea, C. aurea, C. scirpoidea, and Parnassia fimbriata. High soil pH levels (6.4 versus an average of 5.3 for other similarly aged slides) and ample soil moisture probably contributed to the uniqueness in plant composition.

Phantom 1. This was a 36-year-old slide located transitionally between the montane variant of the CWHg subzone and the MH (Mountain Hemlock) zone. Both western hemlock and mountain hemlock (Tsuga mertensiana) were present in the tall and low shrub layers. Sitka spruce and yellow cypress occurred with less cover. On the upper portion of the slide, Calamagrostis nutkaensis formed a dense cover. In the middle and lower portions, herb cover was less dense and consisted of Athyrium filix-femina ssp. cyclosorum, Blechnum spicant, Carex anthoxanthea, C. macrochaeta, Coptis asplenifolia, Cornus unalaschkensis, Epilobium spp., Gymnocarpium dryopteris, Lycopodium selago, Luzula parviflora, Tiarella trifoliata, Viola spp., and Veratrum eschscholtzii.

Rennell 9. This 8-year-old slide was characterized by a very low frequency of tree species and numerous herb species dominated by large patches of the sedge Carex laeviculmis.

South Bay 5. This 14-year-old slide was seeded in 1980 with several agronomic grasses and legumes. The herb layer was dominated by several of these including Agrostis alba, Dactylis glomerata, Deschampsia elongata, Festuca rubra, and Lolium perenne.

Sue Lake 1. The middle and lower portions of this 11-year-old slide were dominated by the herb Equisetum telmateia, not a usual component of slide vegetation. Cover for this species ranged from 70% on the lower portion to 23% in the middle corresponding to decreasing soil moisture from the bottom to the top of the slide. The abundance of E. telmateia was probably related to very moist soils as evidenced by some pools of standing water located in shallow depressions, particularly on the lower slope of the slide.

3) Logged vegetation groups

Three groups (9-11) characterize the vegetation of logged stands. Group 9 represents logged stands between 1 and 7 years of age. Group 10 is typical of older stands up to 25 years of age and dominated by conifers, the most usual situation for logged stands. In contrast, Group 11 describes logged stands with a significant component of red alder. Logged stands over 25 years of age were so heterogeneous that they were not assigned to vegetation groups. However, common species from these plots are documented in Table 18.

Group 9. Total vegetative cover in these young, logged stands is highly variable and appears to be related to the degree of soil disturbance and amount of slash left from logging operations. High total vegetative cover is usually a result of high residual bryophyte cover.

Western hemlock is the dominant conifer in the low shrub layer with a cover usually exceeding 10%. Sitka spruce is also common but its cover rarely exceeds 5%. Western redcedar and yellow cypress are occasionally present but neither exceeds a cover of 1% or a height of 1 m because of browsing by deer. Red alder is also occasionally present but it usually has a cover of less than 1%.

Total shrub cover rarely exceeds 5%. Menziesia ferruginea, Rubus spectabilis, Sambucus racemosa ssp. pubens, and Vaccinium spp. are common.

Herb cover is usually less than 5%. Athyrium filix-femina ssp. cyclosorum, Blechnum spicant, Coptis asplenifolia, Maianthemum dilatatum, and Senecio spp. are common.

Common bryophytes are Dicranum fuscescens, Hylocomium splendens, Plagiothecium undulatum, Polytrichum commune, Rhytidiadelphus loreus, Scapania bolanderi, and Stokesiella oregana.

Group 10. This conifer-dominated, older logged vegetation group has a total plant cover of up to 60%. Western hemlock dominates with a cover of 30-60%. Sitka spruce is also common but has a cover less than 20%. Western redcedar and yellow cypress (CCPH and CWHg2) are often present but because of browsing they are restricted to the low shrub layer and a cover of 1% or less.

Total shrub cover is generally less than 10%. In addition to Rubus spectabilis and Vaccinium spp., Menziesia ferruginea is a common shrub species but it also rarely exceeds a height of 1 m because of browsing by deer.

In general, the cover of herbs is 10% or less. They often occupy exposed areas along the margins of conifer clumps and piles of slash. Common species include Athyrium filix-femina ssp. cyclosorum, Blechnum spicant, Coptis asplenifolia, Luzula parviflora, Maianthemum dilatatum, Polystichum spp., and Trisetum cernuum.

Bryophyte cover is usually less than 50%. Common species are Dicranum fuscescens, Hylocomium splendens, Hypnum circinale, Rhizomnium glabrescens, Plagiothecium undulatum, Polytrichum commune, Rhytidiadelphus loreus, Scapania bolanderi, and Stokesiella oregana.

Group 11. Red alder is the dominant species of this group, present either in the tall shrub or main tree canopy layer. Its cover varies between 35 and 85%. As in young, red alder-dominant, slide plots, red alder suppresses other plant species. Sitka spruce is often the dominant understory conifer but obtains a cover of less than 5%. Western hemlock is even less abundant than Sitka spruce.

In general, shrubs have a cover of less than 5%. Those commonly included are Rubus spectabilis and Vaccinium spp. Menziesia ferruginea and Sambucus racemosa ssp. pubens are occasional components.

Herb cover is usually between 5 and 20%. Common species include Athyrium filix-femina ssp. cyclosorum, Blechnum spicant, Coptis asplenifolia, Dryopteris assimilis, Galium triflorum, Luzula parviflora, Polystichum spp., Prenanthes alata, and Trisetum cernuum.

Bryophyte cover is usually between 20 and 40%. Rhytidiadelphus loreus usually dominates. Other common species are Conocephalum conicum, Dicranum fuscescens, Isopterygium elegans, Pellia spp., Plagiomnium insigne, Plagiothecium undulatum, and Rhizomnium glabrescens.

3.4 Forest Growth and Site Productivity

3.4.1 Early height growth rates of trees

The results of stem analyses of young red alder, Sitka spruce, and western hemlock on slides and in surrounding logged areas are shown in Figure 23. Linear regressions were significantly different between slide and logged areas for all species. For western hemlock and Sitka spruce, height growth in logged stands was about double the rate of that on slides for the same species. Red alder height growth was about twice that of conifers on logged areas and 5 to 6 times that of the conifers on slides (Fig. 23). Height growth of red alder was greater in logged stands than on slides but differences were much less marked than for the conifers. Early height growth on slides was significantly less in the upper slope position for both Sitka spruce and western hemlock.

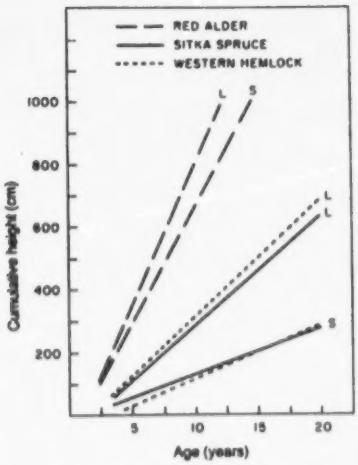

FIGURE 23. Early height growth of red alder, western hemlock, and Sitka spruce in slide (S) and logged (L) areas. R^2 for all regressions >0.99.

3.4.2 Basal area production

As one assessment of productivity, the basal area of stands on slide and logged plots up to 55 years of age were compared. Significantly higher average western hemlock and total conifer basal areas occurred in the logged than in the slide state (Table 19). The total (conifer plus deciduous) basal area averaged more in logged stands than on slides but the difference was not significant (Table 19).

Compared on an age class basis, the basal area of conifers and of conifers plus deciduous trees on logged areas was markedly higher than on similarly aged slides, significantly so for the 30- to 59-year age class (Table 20). The total basal area of conifers in the 30- to 59-year class (avg. = 41 years) of logged stands was even significantly higher than that in the group of slides over 60 years of age (avg. = 85 years) (Table 20). The reverse was true for red alder basal area. No significant difference occurred in total basal area. Old-growth stands had significantly higher average basal areas for conifers than all other age class/state combinations. They also had significantly higher basal area for all species than all other age class/state combinations excepting the 30- to 59 year

TABLE 19. Mean basal area for major tree species for slide and logged stands up to 55 years of age

State	Species[a]						
	Dr	Hw	Ss	Cw	Cy	Total conifer[b]	Grand total[b]
	m^2/ha						
Slide	[c]3.5 a	0.7 b	2.7 a	0.0 a	0.0 a	3.6 b	7.2 a
Logged	3.5 a	4.4 a	3.8 a	0.8 a	0.0 a	9.0 a	12.5 a

[a] Dr = Red alder; Hw = Western hemlock; Ss = Sitka spruce; Cw = Western redcedar; Cy = Yellow cypress.

[b] Includes minor species.

[c] Means within columns followed by the same letter are not significantly different at the 0.05 level (Student-Newman-Keuls' Multiple Range Test).

TABLE 20. Basal area of live trees for slide, logged, and old-growth stands by age class

Age class	State	Basal area		
		Conifer	Deciduous	Total
		----- m^2/ha -----		
1-14	Slide	[a]0.0 e	1.6 b	1.6 d
	Logged	0.9 e	2.8 b	3.7 d
15-29	Slide	0.2 e	9.6 b	9.8 cd
	Logged	12.7 de	2.2 b	14.9 cd
30-59	Slide	16.4 d	5.9 b	22.3 c
	Logged	49.6 b	11.1 b	60.7 ab
60+	Slide	33.7 c	19.7 a	53.4 b
150+	Old growth	63.9 a	0.5 b	64.4 a

[a] Within columns, means followed by the same letter are not significantly different at the 0.05 level (Student-Newman-Keuls' Multiple Range Test).

logged plots (Table 20). In old-growth stands, considerable additional basal area (22 m^2/ha) occurred in dead, standing trees. The greatest contributor to this category was western hemlock (Table 21). Few dead trees were recorded for slides (mainly red alder) and logged stands.

3.4.3 Wood volume production

A considerably lower volume of total bole wood occurred on slides than on logged areas with equivalent age classes (Table 22). Because of low plot numbers in some groups and great variation, differences were only significant for the oldest logged age class, i.e., 30-59 years (Table 22). Conifer volumes were particularly low on slides less than 60 years of age.

The volume ratio of Sitka spruce to western hemlock for the 30- to 59-year age class was higher in slides (10.9:1) than in logged areas (1.1:1) or old growth (0.2:1). Despite this higher ratio on slides, the average total volume of Sitka spruce remained less than in equivalent logged sites.

The percentage reduction of the commercially important conifer volumes on slides versus logged sites was 93, 99, and 72 for 1- to 14-, 15- to 29-, and 30- to 59-year age classes, respectively (Table 22). In the 30- to 59-year class, for example, the greatest reduction occurred at the top of the slide (94%), less at the lower slope (76%), and least at the middle (38%).

In comparison with old (>60 yr) slides (avg. = 85 yr), old-growth stands had significantly larger volumes of western hemlock, western redcedar, and yellow cedar and smaller volumes of red alder and Sitka spruce (Table 23). Even the oldest slides (>80 yr) averaging 107 years had proportionally low covers of hemlock, western redcedar, and yellow cypress and high covers of Sitka spruce and red alder compared with old-growth stands (Fig. 24).

TABLE 21. Mean basal area of dead, standing trees for all slide, logged, and old-growth plots

State	Species[a]					
	Dr	Hw	Ss	Cw	Cy	Total conifer[b]
	- - - - - - - - - - - - m^2/ha - - - - - - - - - - - - - -					
Slide	[c]1.2 a	0.2 b	0.3 a	0.1 b	0.1 b	0.7 b
Logged	0.1 a	0.1 b	0.1 a	0.1 b	0.0 b	0.3 b
Old growth	0.1 a	14.1 a	0.9 a	2.9 a	1.5 a	22.1 a

[a] Dr = Red alder; Hw = Western hemlock; Ss = Sitka spruce; Cw = Western redcedar; Cy = Yellow cypress.

[b] Includes trees not identified at the species level.

[c] Within columns, means followed by the same letter are not significantly different at the 0.05 level (Student-Newman-Keuls' Multiple Range Test).

TABLE 22. Volumes of live trees for slide, logged, and old-growth stands by age class

Age class	State	Volume		
		Conifer	Deciduous	Total
		- - - - - - m^3/ha - - - - -		
1-14	Slide	[a]0.1 c	4.2 b	4.3 c
	Logged	1.4 c	8.8 b	10.2 bc
15-29	Slide	0.5 c	41.7 b	42.2 bc
	Logged	43.0 c	11.0 b	54.0 bc
30-59	Slide	100.0 c	43.1 b	143.1 b
	Logged	353.5 b	123.7 a	477.2 a
60+	Slide	325.2 b	173.2 a	498.4 a
150+	Old growth	669.8 a	4.6 b	674.4 a

[a] Within columns, means followed by the same letter are not significantly different at the 0.05 level (Student-Newman-Keuls' Multiple Range Test).

TABLE 23. Comparison of volumes of trees in old slides (>60 yr) with those in old-growth stands (>150 yr)

State	Species[a]						
	Dr	Hw	Ss	Cw	Cy	Total conifer	Grand total
	- - - - - - - - - - - - - - m^3/ha - - - - - - - - - - - - - -						
Slide (>60 years)	[b]173 a	43 b	262 a	14 b	7 b	325 b	498 b
Old growth	5 b	352 a	86 b	149 a	83 a	670 a	674 a

[a] Dr = Red alder; Hw = Western hemlock; Ss = Sitka spruce; Cw = Western redcedar; Cy = Yellow cypress.

[b] Within columns, means followed by the same letter are not significantly different at the 0.05 level (Student-Newman-Keuls' Multiple Range Test).

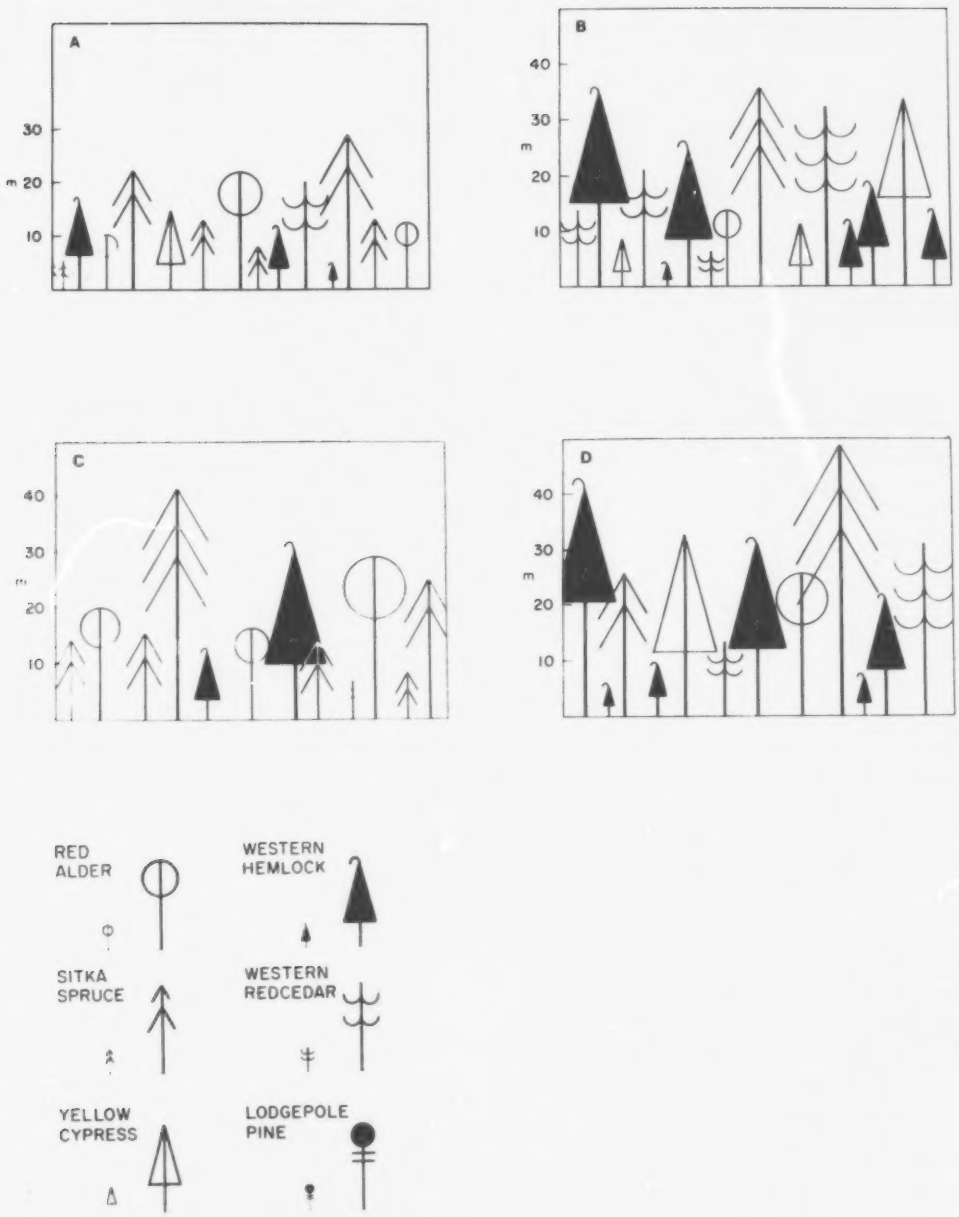

FIGURE 24. Average composition and structure of stands: A. Upper slope, slides >80 years of age; B. Upper slope, old-growth; C. Lower slope, slides >80 years of age; D. Lower slope, old-growth.

4 DISCUSSION

Discussion of differences in landslide characteristics based on slope position (i.e., upper, middle, and lower) refers to debris avalanches in the sense of Swanston and Swanson (1976), which include debris slides, debris flows, and the commonly encountered combinations of these two types (Howes 1981). Debris torrents are not included because they lack a progression from scour at the top to deposit at the bottom. However, the three debris torrents studied are included in total slide summaries of vegetation development and forest productivity.

The average size of landslide studied (2.3 ha) exceeded that for other surveys, e.g., 0.21 ha (Chatwin and Rollerson 1984) and 0.3 ha (Schwab 1983). The larger size in this study reflects its more selective nature and concentration on landslides with well-defined impacts on the site. In addition, large landslides account for most of the total area affected. In a survey of a section of the Queen Charlotte Islands, Rollerson (1984) found that landslides over 1.0 ha in area accounted for only 12% of the number of slides but 67% of the area. In the Rennell Sound area, Schwab (1986) found that slides greater than 0.5 ha in size involved only 25% of the failures but disturbed 67% of the land area. A large size also tends to minimize complicating edge effects such as shading and sloughing of headwall and lateral scarps noted in other studies (Endo and Tsuruta 1966; Hull and Scott 1982; Hupp 1983; Miles et al. 1984; Shimokawa 1984).

The heterogeneity of soil materials, particularly arrangement and depth, prevented a practical stratification into natural zones, e.g., slipface and debris fan (Mark et al. 1964), scour and fill (Adams 1984), or more complex systems (Langenheim 1956). The decision to systematically zone the slides into three thirds of equal length was a compromise that made mapping a heterogeneous surface unnecessary, but it still provided information specific to slope position. The divisions parallel Taylor's (1932) classification of landslides in southeastern Alaska into steep, dry, upper slope, middle slope, and gentle, moist, lower slope. On average, the top two-thirds of slides were partially scoured to bedrock or more rarely to a compact glacial till. The

middle third contained some deposits, the amount and distribution of these depending upon the original topography and the distance from the edge of the slide. The lower third consisted mainly of deposited soil and organic debris. Where debris avalanches were transformed to flows at their lower end, material was often transported completely off the landslide site and into stream channels, thus accounting for the relatively shallow soil even in the lower parts of the slides. Post-failure erosional rills and gullies were present on many of the slide surfaces.

In comparison with surrounding terrain, slides exhibited exaggerated differences in physical characteristics from top to bottom of the slope. Specifically, soil depth increased and bedrock exposure decreased. These features were not significantly different from top to bottom of the slopes adjacent to the slides. While the surrounds were not deemed essentially different from the pre-slide sites, an assumption vital to later comparisons done in the study, average slope gradient on the upper two-thirds of the slides was significantly higher than on the adjacent surround. Thus, the pre-slide site was, on average, steeper or the failure caused an increase in steepness.

The development of vegetation on slide surfaces and the impact of the sliding on forest productivity was related to the nature of post-failure soil materials. The average mid-slide soil was a gravelly sandy loam high in coarse fragments as similarly reported for landslides in Alaska (Adams and Sidle 1984). Compared with the adjacent surround, the upper layers of soils on slides were high in coarse fragments and low in clay and silt. This feature probably resulted from a tumbling action during sliding and a mixing of naturally finer and more completely weathered surface materials with lower horizons, or a removal of upper soil horizons and exposure of relatively coarse subsoil. Additionally, for a number of years after failure slides are particularly sensitive to surface erosion by water (Carr 1983; Rollerson 1984) and sloughing of soil, litter, and woody debris from slide margins. Surface erosion transports fine particles off the slide leaving an armour of coarse fragments on the surface. The over-turning and mixing of soil during sliding also causes a redistribution of surface organic material throughout the soil profile and buries tree boles and other organic debris produced by the slide.

A result of this action is that, except for an initial lack of a surface organic horizon, soils at the mid-slope of slides had average organic carbon levels similar to those in the surrounding soils, i.e., 8% in the upper and 4% in the lower mineral soil profile. Slide soils were, on average, less acid, warmer in the summer, and had a lower C:N ratio than soils in the surround. Given comparable moisture conditions, they have a higher potential for biological activity than those in the surround. However, with establishment of vegetation on the slides and with an apparent increase in acidity of surface organic horizons with time, distinctions between slide and surround should diminish with increasing slide age.

The majority of undisturbed soils in this study were classified as Ferro-Humic or Humo-Ferric Podzols as similarly reported for the Queen Charlotte Islands by Townshend and Bourgeois (1978) and Lewis (1982). After sliding, podzol features such as high iron and aluminum content were sufficiently preserved that even some recent slide soils were classified as podzols, albeit perturbated ones. Some soils were simply truncated pre-slide profiles or overlays on top of pre-slide soils. The percentage of soils classified as podzols increased sharply with increasing age of slides so that the general classification (but not profile detail) of soils on slides over 80 years of age was similar to those in old-growth stands and logged areas. Such rapid "podzolization" contrasts with the slow development on recently exposed moraines (Crocker and Dickson 1957; Sondheim and Standish 1983). This study concluded that most soil material remaining after shallow, debris avalanches is considerably altered from the parent material state in terms of biological, chemical, and physical properties. Though severely disturbed, the soil has not been destroyed and development of plant cover can proceed without a primary phase. Exceptions to this lie in the more limited areas scoured to bedrock or unweathered glacial till.

Although surficial deposits usually consist of materials from a mixture of rock types (Alley and Thomson 1978), there were some apparent relationships between the rock-type classification and certain soil properties. Soils associated with granitic rock were relatively coarse-textured. The coarse conglomerates (Honna formation) were associated with strongly acid soils with

high C:N ratios. Calcareous rock types were associated with relatively high clay contents, low organic carbon contents and low C:N ratios. Hard volcanic rocks were associated with soils high in silt content and with relatively high pH and organic carbon levels. Soils associated with fine sedimentary rocks were high in clay, silt, and organic carbon content.

Principal factors governing the rate and pattern of recovery on slides from a bare surface were soil properties related to associated rock types and slope position. The cover of surface organic matter increased exponentially with age of slide at a significantly faster rate in the lower third than in the middle or upper third. The slowest increase in humus cover was associated with the acid, coarse conglomerate rock type. The fastest occurred with the fine sedimentary rock type and the mixture of types. Although attainment of an organic surface cover was often quite rapid, accumulation to any appreciable depth was extremely slow, presumably because of a high biological activity on slides. Even on the oldest slides sampled, humus depths were less than half those found in logged and old-growth stands. In contrast, Flaccus (1959) observed that organic matter in the surface 10 cm of slides in New Hampshire reached levels in the surrounding forest within 72 years. Relatively high biological activity on the slides studied was also evidenced by the frequent occurrence of a mixed mineral and organic layer (Ah). This condition was, in part, induced by mechanical mixing but also by the action of soil animals. Under a predominant cover of red alder, biological activity was often sufficiently high that only a litter layer existed on the slide surface. For a long period, therefore, slide surfaces remain sensitive to mechanical disturbance. That is, their mineral soil component is not protected by a thick organic mat as it is in logged and old-growth stands. An increase in organic carbon and decrease in pH in humus with increasing slide age signals a shift toward the lower biological activity of old-growth, surface soil. A more rapid increase in humus depth, as observed by other authors for recently exposed moraines (Crocker and Major 1955; Crocker and Dickson 1957; Ugolini 1968), is expected to eventually occur.

The humus of logged and old-growth stands was composed of a greater proportion of rotten wood than that on slides. Recently logged areas had particularly high percentages of rotten wood, probably resulting from additions of decayed material from felled snags and the scattering of rotten, natural logs during logging operations (Smith and Wass 1983). Establishment and growth of western hemlock would be particularly favored by the abundance of rotten wood in logged areas and that of Sitka spruce by the exposed mineral soil and mull-like humus on slides (Krajina 1969).

The shallow soils, bedrock exposure, and susceptibility to erosion on the steep, upper, and middle thirds of slides resulted in a slow increase in total vegetative cover relative to the lower slope. Since no significant differences in cover occurred among slope positions on immediately adjacent logged or old-growth areas, the differences on slides resulted from the sliding itself. Especially sparse vegetation occurred on upper slopes of slides associated with coarse conglomerate, granitic, and hard volcanic rock types. These types were also characterized by minimal establishment of red alder. In contrast, particularly rapid revegetation, especially of red alder, occurred on lower slopes in association with calcareous and fine sedimentary rock types and mixtures. Sitka spruce seemed to have some of the same substrate preferences as red alder and, as observed by Taylor (1934), contrasts sharply with western hemlock in this respect. The occurrence of red alder on logged areas was local and reached significant numbers only in association with fine sedimentary rock types.

In general, forest composition was related most clearly to associated rock type on slides and less clearly in logged areas, and there was little correlation in old growth. These findings suggest that as surface organic material accumulates causing changes in the surface mineral soil and as red alder declines in importance, the upper soil profile and the composition of the forest become less and less influenced by the nature of the parent material. However, productivity of old-growth stands in the Queen Charlotte Islands has been correlated with bedrock types (Warren and Matheson 1949; Lewis 1982).

Total vegetative cover on logged areas exceeded that on slides when similar ages were compared because of residual vegetation left after logging, and the presence on logged areas of relatively deep, stable soils. By 100 years, average vegetative cover for both states exceeded the average for old-growth stands. This result implies that vegetative cover on slides and logged areas will eventually decrease as a result of natural mortality and windthrow.

In contrast to early reports of a dense and vigorous shrub and herb cover on the Queen Charlotte Islands (Hopkinson 1931), these components were not dominant in any of the three states--logged, slide, or old growth. As described for old-growth stands by Pojar and Banner (1984), both the vigor and cover of herbs and shrubs appeared severely reduced by the browsing of deer introduced during the first quarter of the 20th century (Cowan 1956). Bryophytes, however, developed unmolested and increased in cover steadily after slope failure and logging to a level considerably higher than in old-growth stands. Alaback (1982) showed bryophyte biomass increasing sharply after logging of spruce-western hemlock forests to about 125 years, then decreasing to about 60% of that level in stands over 300 years. This study predicts a similar decrease in bryophyte cover on slides older than the ones studied, as natural mortality causes increased stand opening.

On average, stocking of trees on slides and in logged areas reached levels satisfying reforestation standards. However, distribution was often clumped and dependent on suitable, stable substrates, particularly in the upper portions of slides. Patchiness in logged stands was more often the result of concentrations of slash preventing tree establishment and growth. Based on number of stems, western hemlock was most numerous particularly on the upper slope positions of slides, a similar result to that reported by Taylor (1932) for landslides in Alaska. Western hemlock was also more numerous in the upper slopes of logged stands than the lower. High numbers of western hemlock were associated with granitic rock types and high numbers of red alder with calcareous rock types. When percentage composition was expressed by either number of stems or basal area, western hemlock emerged as the dominant tree species in logged and old-growth stands. The dominant trees by basal area for

slides were red alder and Sitka spruce. Although western redcedar and yellow cypress were present in significant amounts in old-growth stands, their contribution to logged stands was small. This may reflect just slow growth rates or may indicate increasing impacts of deer in the past 50 years. As observed for old-growth stands (Pojar and Banner 1984), western redcedar and yellow cypress are utilized by deer on slides and logged areas at a significantly higher level than Sitka spruce and western hemlock.

There are several reasons for the difficulty in describing homogeneous vegetation groups that reflect a discrete set of site conditions. Landslide surfaces were often extremely heterogeneous, i.e., bare mineral soil versus rubble versus bedrock versus organic debris and moist gullies versus drier ridges. In addition, logs and stumps created their own shaded microsites. This variability meant that only the most common and abundant species were repeatedly recorded in plots within seemingly comparable vegetation. Browsing by deer may have resulted in the elimination of important indicator species or, at least, reduced their role. Differences in browsing intensity noted from area to area would cause variation additional to that caused by physical site conditions. Reduced access to vegetation for deer caused by small cliffs, large stumps, slash, and debris also cause differences in vegetative composition and cover not directly related to the sites capacity to support plant growth.

Despite the aforementioned problems, some general trends in revegetation of slides are evident. The dominant course for revegetation on slides is governed by an abundant cover of red alder. On logged areas, the major trend involves sparse to dense conifer cover, particularly western hemlock and Sitka spruce. Less commonly, conifers dominate particular portions of slides and red alder may be an important component of logged-over areas. Eleven plant groups were recognized as representing major stages and characteristics of vegetative recovery. Factors involved in shaping these groups include time since logging or slide failure, biogeoclimatic zone, and physical and chemical characteristics of the substrate including soil depth, percentage bedrock exposure, soil texture, nature of associated rock type, seepage, soil stability, and degree of surface erosion.

The forest productivity of slides is reduced by about 70% when compared with that of similarly aged logged stands. This productivity difference arises primarily from lower growth rates and stocking of upper slide areas and severe competition from red alder in middle and especially lower slide positions. Early height growth of Sitka spruce and western hemlock on slides was about half that in logged areas. Miles et al. (1984) showed reduction in height growth of Douglas-fir on landslides of 38% for trees up to 18 years of age when compared with growth on logged areas. Red alder also establishes in some logged areas but the advance regeneration of conifers seems better able to offset the rapid growth of alder than does new regeneration of conifers on slides. Although Sitka spruce production exceeded western hemlock on slides, logged areas still produce a greater average volume of spruce than similarly aged slides.

Since logged stands over 55 years of age were not sampled, it was not possible to directly determine whether a 70% reduction in volume production would continue to rotation age. However, as revegetation continues and soils stabilize, productivity on slides can be expected to increase. The total volume for slides 60 years of age and older (avg. = 85 years) was 498 m^3/ha. This volume can be compared with the approximately 900 m^3/ha for second-growth stands of site index 36 m at 100 years on undisturbed areas at the same age (Taylor 1934). The indicated reduction at 85 years would then be about 45% for total volume and 65% for conifers only. Even without active management, productivity on slides should recover gradually in subsequent rotations. However, Trustrum et al. (1984) postulated that slides in New Zealand may never reach their former level of productivity. This may well be true for the upper portions of most slides.

Early establishment of Sitka spruce by planting and at least partial control of red alder on the relatively stable and productive lower slopes of slides would increase production of conifers appreciably. In contrast, the extreme upper portions of slides will suffer from reduced productivity for an extended period. Establishment or enhancement of species such as Sitka alder (Alnus sinuata) and other nitrogen-fixing plants should accelerate the recovery process on these upper slopes.

5 SUMMARY

1. Debris avalanches change the character of the terrain such that soils on the upper two-thirds of the slides are shallower, coarser, and include more bedrock exposure than the original soils.
2. Though severely perturbed, soils on slides retain many of the characteristics of the original podzol soil, i.e., high organic carbon, iron, and aluminum levels. Except for areas of bedrock exposure and very thin soils, revegetation on slides occurs on secondary (modified) rather than primary soil materials. Plant species colonizing slides are not markedly different from those on adjacent logged stands or old growth. However, greater differences do exist in plant vigor, relative abundance of species, and distributional patterns.
3. The lower half of recent landslides is generally colonized by red alder, particularly in association with calcareous, fine-textured sedimentary or mixed rock types. Sitka spruce and western hemlock are suppressed by red alder. When the red alder component deteriorates at 70-90 years of age, the released conifers are often at suboptimum stocking levels.
4. The upper portions of slides are normally first colonized by conifers -- western hemlock mainly, but also Sitka spruce. These conifers exhibit relatively slow growth and a clumped distribution as a result of poor growing conditions. Red alder may establish at a later stage, provided mineral soil is still exposed, as seed becomes available from maturing alder lower on the slides.
5. Occasionally, conditions exist on slides in which soil conditions are favorable for tree growth and where red alder fails to become a serious competitor. In these situations, stands consisting largely of Sitka spruce may be very productive.
6. In comparison with adjacent logged stands in the same age class (30-59 years), the average slide produces 70% less wood volume. Projections using yield tables for older second-growth stands and data from this study for the oldest class of slides indicate that the reduction

at 85 years would be about 45%. Considering the conifer component only, reductions are calculated as 72% at 55 years and 65% at 85 years.

7. Slow vegetative recovery on slides (48% cover at 40 years) is associated with upper slope positions and especially with coarse conglomerate and hard volcanic rock types. This slow recovery also tends to correspond with a low rate of red alder colonization. Rapid vegetative recovery (83% cover at 40 years) is associated with lower slopes and with calcareous and fine sedimentary rock types.
8. Most species of shrubs and many herbs are severely browsed by deer thus reducing their role in vegetative recovery and possibly lessening their role in restoring root-related soil strength after landslides and clearcutting. Tree species are also seriously damaged by browsing. That western redcedar and yellow cypress are especially utilized by deer may partially explain why these species are abundant as seedlings on young slides yet play a minor role in terms of volume in older slides.
9. Despite an exponential increase in vegetation and organic surface cover, high biological activity on slides -- induced by high soil temperatures, low C:N ratios, and reduced acidity relative to non-slide soils -- is instrumental in preventing a build-up of humus anywhere near the depths found in logged and old-growth stands. Any logging of stands developed on slides should be conducted with care to minimize mineral soil exposure and the potential for renewed surface soil erosion.

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APPENDIX 1. Characteristics of failures and their surrounds

Location	Identity No.	Slide age	Type[a]	BGC[b] zone	Bedrock-mapped[c] 1	2	Rock collected[d] Bedrock 1	2	Surficial 1	2	Summary rock class[e]	Range in elev. (m)	Average aspect (deg)	Area (ha)	Surround[f] 1	2
Burnaby	1	36	DA	CWHg	PTP	-	G	-	G	-	1	4-398	186	4.9	Old growth	-
Burnaby	2	38	DA	CWHg	PTP	-	G	-	G	-	1	5-228	336	2.8	Old growth	-
Deena	1	3	DA/DF	CWHg	Karmutsen	-	HV(b)	-	HV(b)	-	4	100-325	170	1.6	Logged 1975-76	Old growth
Deena	2	75&30	DA/DT/DF	CWHg	Kunga	Karmutsen	CaFSe	-	CaFSe	-	5	100-427	175	4.6	Old growth	-
Deena	3	g	g	CWHg	Honna	-	CnGSa	-	CnGSa	-	2	0-138	006	1.4	Logged-1966	-
Hangover	1	155	DA	CCPH	Masset	-	SV(a)	-	SV(a)	-	3	50-300	250	15.5	Old growth	-
Juskatla	1	35	DA	CWHg	Masset	-	G	-	G	-	1	250-470	098	4.0	Old growth	-
Juskatla	2	7	DA	CWHg	Masset	-	SV(a)	-	SV(a)	-	3	240-323	215	0.4	Logged-1967	-
Juskatla	3	14	DA	CWHg	Masset	-	SV(b)	-	SV(b)	-	3	75-175	63	0.5	Logged-1965	-
Juskatla	4	87	DA	CWHg	Masset	-	SV(n)	G	SV(n)	G	3,1	150-520	280	2.8	Old growth	-
Kaisun	1	32 & 4	DA	CCPH	Karmutsen	Kunga	CaSV	HV(b)	CaSV	HV(b)	5,4	0-308	160	1.8	Old growth	-
Kaisun	3	125,73&4	DA	CCPH	Karmutsen	-	HV(b)	-	HV(b)	-	4	100-300	160	-	Old growth	-
Kaisun	4	70	DA	CCPH	Karmutsen	Kunga	SV(b)	CaFSe	SV(b)	CaFSe	3,5	0-385	165	-	Old growth	-
Long Inlet	1	21	DA	CWHg	Honna	-	CoSe	CaFSe	CoSe	CaFSe	2,5	3-341	234	1.0	Old growth	Logged-1982
Marshall	1	38	DA	CCPH	Karmutsen	-	HV(b)	-	HV(b)	-	4	0-95	357	0.6	Old growth	-
Mosquito	1	30 & 3	DA/DF	CWHg	Karmutsen	-	CaHV	-	CaHV	-	5	30-213	343	0.6	Logged-1946	-
Mosquito	2	3 & 9	DA	CWHg	Karmutsen	-	HV(n)	-	HV(n)	-	4	31-134	164	0.6	Logged-1946	-
Peel	1	25	DA	CWHg	Karmutsen	-	HV(b)	-	HV(n)	HV(a)	4	140-340	174	1.1	Logged-1957	Old growth
Phantom	1	36	DA/DF	CWHg-MH	Yakoun	-	CaFSe	-	SV(b)	-	7	450-550	056	0.4	Old growth	-
Rennell	1	1	DA/DF	CCPH	PTP	-	G	-	G	-	1	90-130	030	0.1	Logged-1977	-
Rennell	2	3	DA/DF	CCPH	Kunga	-	CaFSe	G	CaFSe	G	1,5	80-250	050	0.8	Logged-1977	Old growth
Rennell	3	3	DT	CCPH	Yakoun	-	SV(b)	-	SV(b)	-	3	122-425	164	1.2	Logged-1974	-
Rennell	4	64	DA/DF	CCPH	Yakoun	-	SV(b)	-	SV(b)	-	3	152-490	040	1.3	Old growth	-

APPENDIX 1. (Continued)

Location	Identity No.	Slide age	Type[a]	BGC[b] zone	Bedrock-mapped[c] 1	2	Rock collected[d] Bedrock 1	2	Surficial 1	2	Summary rock class[e]	Range in elev. (m)	Average aspect (deg)	Area (ha)	Surround[f] 1	2
Rennell	5	62	DA	CCPH	Kunga	-	FSe	-	FSe	-	6	0-270	240	3.8	Logged-1973	Old growth
Rennell	6	9	DA	CCPH	Kunga	-	FSe	-	FSe	-	6	60-280	344	3.5	Logged-1971/72	-
Rennell	7	87	DA	CCPH	Karmutsen	-	HV(b)	G	HV(b)	G	4,1	70-220	046	1.6	Old growth	-
Rennell	8	99	DA	CCPH	Yakoun	-	SV(a)	CaFSe	SV(a)	CaFSe	3,5	150-342	018	1.1	Old growth	-
Rennell	9	8	DA	CCPH	Kunga	-	FSe	-	G	SV(b)	7	38-128	251	0.5	Logged-1971	Old growth
Rennell	10	4	DA/DF	CCPH	PTP	-	G	-	G	-	1	40-220	187	1.8	Logged-1966	Old growth
Rennell	11	45	DA	CCPH	Yakoun	-	FSe	CaSV	CaSV	FSe	5,7,6	180-368	335	2.2	Old growth	-
Sachs	1	7	RS	CWHg	Honna	-	CnGSa	-	CnGSa	-	2	250-290	328	0.1	Logged-1975	-
Sachs	2	8	DA/DT	CWHg	Honna	-	CnGSa	-	CnGSa	-	2	440-530	273	0.8	Logged-1970	-
Sachs	3	12	DA	CWHg	Honna	-	CnGSa	-	CnGSa	-	2	355-488	164	1.2	Old growth	-
Sachs	4	48	DA	CWHg	Honna	Haida	CnGSa	FSe	CnGSa	FSe	2,6	316-595	098	3.1	Old growth	-
Sewell	1	60 & 3	DA/DT	CWHg	Masset	-	SV(b)	-	SV(b)	-	3	85-450	124	3.4	Logged-1973-80	-
Sewell	2	8	DA	CWHg	Haida	Honna	SV(a)	-	SV(a)	-	3	0-134	345	1.4	Logged-1950	-
Sewell	3	20	DA	CWHg	Haida	-	FSe	SV(n)	FSe	SV(n)	7	22-161	142	1.1	Logged-1937	-
Sewell	4	23	DA	CWHg	Haida	-	SV(a)	-	SV(a)	-	3	128-410	082	2.2	Old growth	-
Sewell	5	33	DA	CCPH	Karmutsen	-	SV(a)	-	SV(a)	-	3	28-215	323	1.0	Old growth	Logged - 1967
Sewell	6	25	DA	CCPH	Karmutsen	-	HV(b)	-	HV(b)	-	4	20-222	216	0.9	Old growth	Logged - 1981
South Bay	1	3 & 11	DA/DT	CWHg	Honna	-	CnGSa	-	CnGSa	-	2	383-563	320	1.9	Logged-1977-80	-
South Bay	2	3	RS/DT	CWHg	Haida	Kunga	CoSe	CaFSe	CoSe	CaFSe	2,5	30-215	319	2.1	Logged-1969-72	-
South Bay	3	3	DT	CWHg	Honna	Haida	CnGSa	-	CnGSa	-	2	166-433	198	4.3	Logged-1960-71	-
South Bay	4	2 & 7	DA/DF	CWHg	Honna	Haida	CnGSa	FSe	CnGSa	-	2,7	460-543	106	0.2	Logged-1972	-
South Bay	5	14	DA	CWHg	Honna	-	CnGSa	-	CnGSa	-	2	340-442	215	0.7	Old growth	-
Sue Lake	1	11	DA	CWHg	Yakoun	-	CaCoSa	-	CaCoSa		5	215-355	155	2.8	Logged-1971	-

APPENDIX 1. (Continued)

Location	Identity No.	Slide age	Type[a]	BGC[b] zone	Bedrock-mapped[c] 1	2	Rock collected[d] Bedrock 1	2	Surficial 1	2	Summary rock class[e]	Range in elev. (m)	Average aspect (deg)	Area (ha)	Surround[f] 1	2
Talunkwan	1	67	DA	CWHg	PTP	-	G	-	G	-	1	0-290	150	1.5	Old growth	-
Talunkwan	2	14	DA	CWHg	Masset	-	HV(b)	-	HV(b)	-	4	0-315	182	4.1	Logged-1927	Old growth
Yakoun	1	102	DA	CWHg	Yakoun	-	SV(a)	-	SV(a)	-	3	155-488	066	3.5	Old growth	-
Yakoun	2	104	DA	CCPH	Longarm	-	FSe	-	FSe	-	6	105-482	140	12.3	Old growth	-

[a] DA = Debris avalanche; DF = Debris flow; DT = Debris torrent; RS = Rotational slump (Swanston 1974).

[b] BGC = Biogeoclimatic: CWHg = Queen Charlotte Island Hemlock - Cedar - Spruce Subzone of the Coastal Western Hemlock Zone; CCPH = Coastal Cedars - Pine Hemlock Zone; MH = Mountain Hemlock Zone.

[c] 1 = Major component; 2 = Minor component. Formations mapped by Sutherland Brown (1968): PTP = Post-Tectonic Plutons;

[d] 1 = Major component; 2 = Minor component; G = Granitic, mainly Post-Tectonic Plutons; HV = Hard volcanics, mainly Karmutsen; SV = Soft volcanics mainly Masset and Yakoun; CnGSa = Conglomerate Granitic (cobbles) Sandstone, Honna; FSe = Fine sedimentary, mainly Kunga, Haida, Longarm; CoSe = Coarse sedimentary, mainly Haida, Longarm; Ca = Calcareous; (a) = acid, mainly rhyolite; (b) = basic, mainly andesite and basalt; (n) = neutral, mainly mixtures of acid and basic volcanics.

[e] Major rock types: 1 = Granitic; 2 = Coarse sandstone and conglomerate; 3 = Soft volcanic; 4 = Hard volcanic; 5 = Calcareous; 6 = Fine sedimentary; 7 = Mixture. Multiple numbers indicate that plots on a failure were associated with more than one major rock type.

[f] 1 = Major component; 2 = Minor component.

[g] Not a failure. Yarding disturbance only.

APPENDIX 2. List of plant species recorded[1]

Trees

Alnus rubra Bong.
Alnus sinuata (Reg.) Rydb.
Chamaecyparis nootkatensis (D. Don) Spach
Picea sitchensis (Bong.) Carr.
Pinus contorta Dougl.
Taxus brevifolia Nutt.
Thuja plicata Donn
Tsuga heterophylla (Raf.) Sarg.
Tsuga mertensiana (Bong.) Carr.

Shrubs

Aruncus sylvester Kostel.
Gaultheria shallon Pursh
Menziesia ferruginea Smith
Oplopanax horridus (Sm.) Miq.
Ribes bracteosum Dougl. in Hook.
Ribes lacustre (Pers.) Poir. in Lam.
Ribes laxiflorum Pursh
Rubus parviflorus Nutt.
Rubus spectabilis Pursh
Sambucus racemosa L. ssp. pubens (Michx.) House
Vaccinium alaskaense Howell
Vaccinium ovalifolium Smith in Rees
Vaccinium parvifolium Smith in Rees

Herbs

Adiantum pedatum L. ssp. aleuticum (Rupr.) Calder & Taylor
Agrostis aequivalvis (Trin.) Trin.
Agrostis alba L.[2]
Agrostis exarata Trin.
Agrostis scabra Willd.
Anaphalis margaritacea (L.) Benth. & Hook.
Aquilegia formosa Fisch. in DC.
Athyrium filix-femina L. (Roth.) ssp. cyclosorum (Rupr.) C. Chr. in Hult.
Barbarea orthoceras Ledeb.
Blechnum spicant (L.) With.
Botrychium multifidum (Gmel.) Rupr. ssp. silaifolium (Presl) Clausen
Calamagrostis nutkaensis (Presl) Steud.
Caltha biflora DC.
Campanula alaskana (A. Gray) Wight: J.P. Anderson
Cardamine pensylvanica Muhl.: Willd.
Carex anthoxanthea Presl

Carex aurea Nutt.
Carex deweyana Schw. ssp. leptopoda (Mackenzie) Calder & Taylor
Carex disperma Dewey
Carex laeviculmis Meinsh.
Carex macrochaeta C.A. Meyer
Carex mertensii Prescott in Bong.
Carex obnupta Bailey
Carex phyllomanica W. Boott in S. Wats.
Carex scirpoidea Michx.
Carex stylosa C.A. Meyer
Carex viridula Michx.
Cerastium vulgatum L.
Cirsium arvense (L.) Scop.
Cirsium brevistylum Cronq.
Cirsium vulgare (Savi) Airy-Shaw
Coptis asplenifolia Salisb.
Corallorhiza maculata Raf. ssp. mertensiana (Bong.) Calder & Taylor
Cornus unalaschkensis Ledeb.
Cystopteris fragilis (L.) Bernh.
Dactylis glomerata L.[2]
Deschampsia caespitosa (L.) Beauv. ssp. beringensis (Hult.) Lawr.
Deschampsia elongata (Hook.) Munro: Benth.
Digitalis purpurea L.
Drosera rotundifolia L.
Dryopteris assimilis S. Walker
Epilobium delicatum Trel.
Epilobium glandulosum Lehm.
Equisetum arvense L.
Equisetum telmateia Ehrh.
Erigeron peregrinus (Pursh) Greene
Festuca occidentalis Hook.
Festuca rubra L.
Festuca subulata Trin. in Bong.
Galium triflorum Michx.
Gnaphalium purpureum L.
Gnaphalium uliginosum L.
Gymnocarpium dryopteris (L.) Newman
Habenaria chorisiana Cham.
Habenaria saccata Greene
Heuchera glabra Willd.: R. & S.
Hieracium albiflorum Hook.
Holcus lanatus L.
Juncus effusus L.
Juncus ensifolius Wikstr.
Lactuca biennis (Moench) Fernald
Listera caurina Piper
Listera cordata (L.) R.Br. in Ait.
Lolium perenne L.[2]

Lolium temulentum L.
Luzula multiflora (Retz.) Lejeune
Luzula parviflora (Ehrh.) Desv.
Lycopodium annotinum L.
Lycopodium clavatum L.
Lycopodium inundatum L.
Lycopodium selago L.
Lysichiton americanum Hult. & St. John
Maianthemum dilatatum (Wood) Nelson & Macbr.
Moneses uniflora (L.) Gray ssp. reticulata (Nutt.) Calder & Taylor
Montia fontana L.
Montia siberica (L.) Howell
Osmorhiza purpurea (Coult. & Rose) Suksd.
Parnassia fimbriata König
Pinguicula vulgaris L. ssp. macroceras (Link) Calder & Taylor
Poa annua L.
Polypodium vulgare L. ssp. occidentale (Hook.) Hult.
Polystichum lonchitis (L.) Roth: Roem.
Polystichum munitum (Kaulf.) Presl
Prenanthes alata (Hook.) D. Dietr.
Ranunculus repens L.
Ranunculus uncinatus D. Don in G. Don
Rubus pedatus Smith
Sagina maxima A. Gray
Sagina procumbens L.
Saxifraga ferruginea Grah.
Senecio newcombei Greene
Senecio sylvaticus L.
Senecio vulgaris L.
Sonchus asper (L.) Hill
Stellaria calycantha Bong.
Stellaria crispa Cham. & Schlecht.
Stellaria media (L.) Vill.
Streptopus amplexifolius (L.) DC.
Streptopus roseus Michx. ssp. curvipes (Vail) Hult.
Streptopus streptopoides (Ledeb.) Frye & Rigg ssp. brevipes (Baker) Calder & Taylor
Taraxacum officinale Weber in Wiggers
Tellima grandiflora (Pursh) Dougl. in Lindl.
Thelypteris phegopteris (L.) Slosson in Rydb.
Tiarella trifoliata L.
Tolmiea menziesii (Pursh) T. & G.
Trientalis europaea L.
Trifolium repens L.[2]
Trisetum cernuum Trin.
Veratrum eschscholtzii A. Gray
Veronica americana Schwein.: Benth. in DC.
Veronica serpyllifolia L.
Viola glabella Nutt. in T. & G.

Mosses, Liverworts, and Lichens

Atrichum selwynii Aust.
Bartramia pomiformis Hedw.
Blepharostoma trichophyllum (L.) Dum.
Blindia acuta (Hedw.) B.S.G.
Brachythecium asperrimum (C. Muell.) Sull.
Buxbaumia piperi Best
Calypogeia sp.
Cephalozia bicuspidata (L.) Dum.
Ceratodon purpureus (Hedw.) Brid.
Cladina sp.
Cladonia sp.
Conocephalum conicum (L.) Lindb.
Dicranella heteromalla (Hedw.) Schimp.
Dicranum fuscescens Turn.
Dicranum majus Turn.
Dicranum scoparium Hedw.
Diplophyllum albicans (L.) Dum.
Drepanocladus aduncus (Hedw.) Warnst.
Fissidens adianthoides Hedw.
Fissidens osmundoides Hedw.
Hookeria lucens (Hedw.) Sm.
Hylocomium splendens (Hedw.) B.S.G.
Hypnum circinale Hook.
Isopterygium elegans (Brid.) Lindb.
Isothecium spiculiferum (Mitt.) Ren. & Card.
Lepidozia reptans (L.) Dum.
Leucolepis menziesii (Hook.) Steere in L. Koch
Metzgeria furcata (L.) Dum.
Mnium spinulosum B.S.G.
Oligotrichum aligerum Mitt.
Pellia spp.
Peltigera spp.
Pilophoron aciculare Ach. Nyl.
Plagiochila asplenioides (L.) Dum.
Plagiomnium insigne (Mitt.) Koponen
Plagiothecium undulatum (Hedw.) B.S.G.
Pogonatum alpinum (Hedw.) Roehl.
Pogonatum contortum (Menz.: Brid.) Lesq.
Pohlia nutans (Hedw.) Lindb.
Polytrichum commune Hedw.
Polytrichum juniperinum Hedw.
Rhacomitrium canescens (Hedw.) Brid.
Rhacomitrium heterostichum (Hedw.) Brid.
Rhizomnium glabrescens (Kindb.) Koponen
Rhytidiadelphus loreus (Hedw.) Warnst.
Riccardia spp.

Scapania bolanderi Aust.
Sphagnum spp.
Splachnum rubrum Hedw.
Stokesiella oregana (Sull.) Robins.
Tetraphis pellucida Hedw.
Tortella tortuosa (Hedw.) Limpr.

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[1] Nomenclature mainly from Hosie (1969) for trees, Calder and Taylor (1968) for other vascular plants, Lawton (1971) for mosses, and Conard and Redfearn (1979) for liverworts.

[2] Recorded in slide SB-5 aerially seeded in 1980 with grasses and legumes.